A WHOLE WORD AND NUMBER
READING MACHINE BASED ON
TWO DIMENSIONAL LOW FREQUENCY
FOURIER TRANSFORMS

DISSERTATION

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AFIT/DS/ENG/90D-01

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Presented to the Faculty of the School of Engineering
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Doctor of Philosophy

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Preface

This research investigates the use of Fourier transforms as a means for developing an optical reader. The approach is to treat whole words or entire numbers as single symbols. Instead of segmenting a word into its individual characters, the whole image of a word is treated as a single symbol. Where as segmenting a word into characters requires only a vocabulary of the letters a-z and A-Z, recognition of words as single symbols requires a vocabulary of thousands of words. The advantage though is segmenting words has proven to be fruitless, especially with the advance of the laser printer, and segmenting *between* the words in a sentence is a task which has been solved. Therefore, a reading machine that can distinguish whole words and that has a large enough vocabulary will make a superior optical reader to what is currently available.

This PhD program has been the greatest learning experience for me, mentally and spiritually. Mentally, it was challenging and stimulating to investigate and explore new thoughts and concepts. Spiritually, it gave me an insight to just how much I don't know and how omniscient God really is. So many times when I hit a wall in my research I cried out to God for an answer and every time He carried me through. When it was not within me to pass a test or solve a new problem, God gave me the wisdom. If having outside help is cheating, then I cheated the entire program by the help of Jesus Christ. I stood daily upon the scripture: "If any of you lacks wisdom, he should ask of God, who gives generously to all without finding fault, and it will be given to him." [James 1:6, NIV]

First a special thanks to my advisor Dr. Kabrisky who defended my qualifications for entrance into the program and who gave my research the needed adjustments to maintain a proper focus of my desired goals. Eventhough he originally insisted my concept of identifying words as wholes would never work, he still supported my efforts and gave me the opportunity to try. To Amy Krafcik and Walt Jurek my editors and friends, thanks for helping me deliver a quality product. Also to Ron Eddy and Anthony Schooler, thanks for keeping the computers running and for your software expertise. To my wife Beth who provided about 90% of my motivation to keep working and to always do my best, I say; *we* finished. But most of all, I've learned from this program that a degree, or knowledge, or wealth, or whatever seems desirable is usually temporal. One's priorities should always be towards something that is everlasting; Jesus Christ. "But seek *first* His kingdom and His righteousness, and all these things will be given to you as well." [Matt 6:33, NIV]

Mark Allen O'Hair

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Abstract

The Fourier transform is investigated as a means for developing an optical reader capable of reading a large vocabulary without segmenting the image of a word into individual characters. The reader is capable of reading printed and cursive font styles, is scale invariant, and is substantially insensitive to noise. The image of a particular word is treated as a single symbol; the two dimensional low frequency Fourier coefficients (assuming n coefficients are calculated) define the word's location on an n dimensional hypersphere of unit radius. The distance between individual locations (words) categorizes similar and dissimilar words. The smaller the distance, the more similar two images are. Multiple images of a word using various font styles form a unique cluster on the surface of the hypersphere. The distance between clusters (different words) is greater than the distance across a cluster (same word in different font styles). Therefore, by using the centroid of these clusters to build a library of words, input or test words match to the nearest cluster centroid using a minimum distance calculation. This algorithm is capable of correctly recognizing at least 5000 words using 24 various font styles (120,000 individual images). (KR)

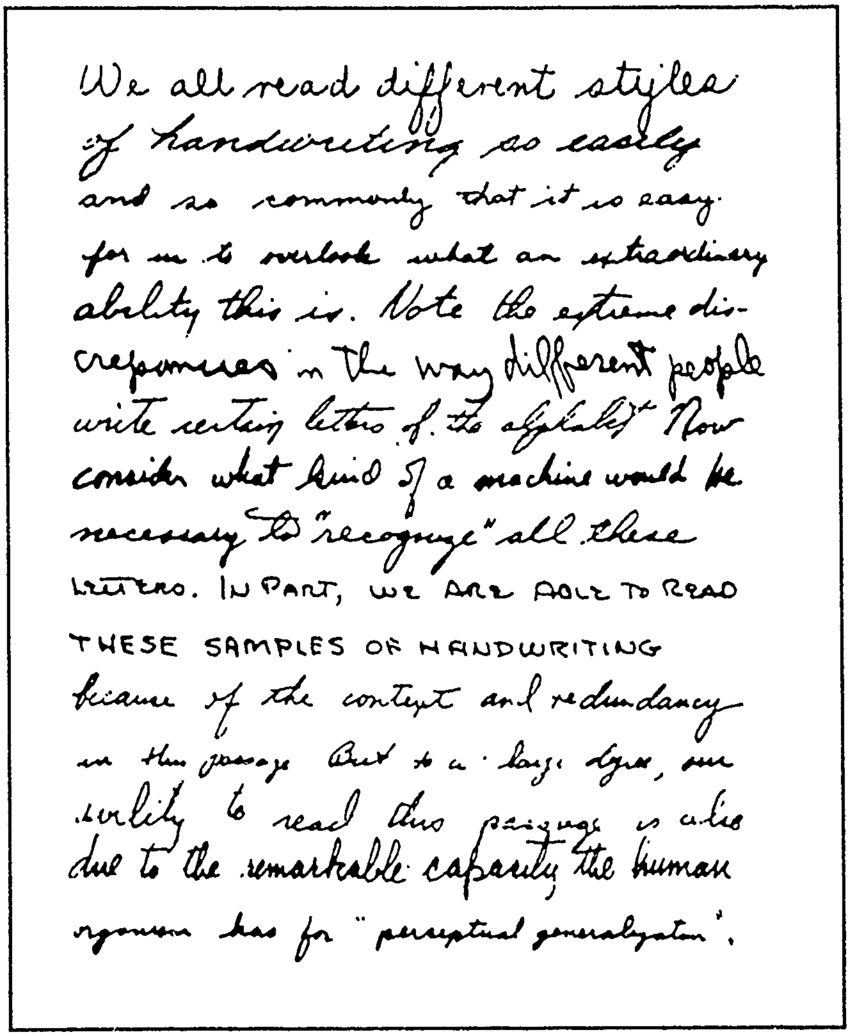
A WHOLE WORD AND NUMBER READING MACHINE BASED ON TWO DIMENSIONAL LOW FREQUENCY FOURIER TRANSFORMS

I. Introduction

The objective of this research was to investigate the use of the Fourier Transform as a means for developing an optical reader that is scale invariant and not limited by font shapes or spacing. With the development of laser printers, the evenly spaced text from the standard typewriter or daisy wheel printer becomes a thing of the past. Text is now more italicized, ornate, and varied in letter spacing. Now, these three characteristics have become a stumbling block to present day optical character readers (OCR's). The OCR depends upon segmenting a word into letters and then reconstructing the entire word. But what if segmenting a word into individual letters is not required? The boundaries which exist between words and lines are quite apparent but between individual letters they are not.

Under these circumstances an optical reader independent of letter segmentation could read almost any text as long as it has an appropriate template. This includes italicized and even possibly script (cursive) fonts. What seems impossible on a computer is being done within the human brain as one reads the text in Figure 1.

With the vast difference in hand writing, the above text is still discernable. This process of identifying text is hypothesized by the Gestalt Theory. It theorizes how the brain identifies the numerous font types or objects based on associations with partial or similar learned images. No two *the*'s are exactly shaped the same. Yet how difficult was it to read the last *the*? The brain has stored a vast quantity of different *the*'s, yet as long as the font type is not too strange, it is read. Association is not dependent on segmenting the letters within a word, except when the words are unfamiliar or very long, but the image of a word is treated as a single symbol. Consequently, laser printing italic or script font is



We all read different styles of handwriting so easily and so commonly that it is easy for us to overlook what an extraordinary ability this is. Note the extreme discrepancies in the way different people write certain letters of the alphabet. Now consider what kind of a machine would be necessary to "recognize" all these LETTERS. IN PART, WE ARE ABLE TO READ THESE SAMPLES OF HANDWRITING because of the context and redundancy in this passage. But to a large degree, our ability to read this passage is also due to the remarkable capacity the human organism has for "perceptual generalization".

Figure 1. Samples of Hand Writing

(4:196)

easy for the brain to decipher but almost impossible for an OCR. However, a gestalt based reader solves this dilemma.

My Masters' thesis (13) explored an approach to recognizing text as whole words without letter segmentation. In my research, I used 200 capital words with fixed letter spacing and some variation in font style. The thesis conclusions reveal that Fourier Transforms can model the gestalt of whole words, but it did not answer the question: is a working vocabulary with many various font styles possible? The thesis was quite successful as a test case for identifying whole words, but it was very limited in scope. A working vocabulary needs to be much larger and include lower case letters. Font variation increases greatly with the use of lower case, which adds to the complexity of the problem.

The system proposed above digitizes the image of a letter or word and forms the two dimensional Discrete Fourier Transform (2DFT). The coefficients from this transform are then used to categorize the original image. The smaller the difference there is in coefficient values the higher the correlation to similar looking input images.

The scope of this investigation is to use the lower harmonics of the 2DFT as a feature set in which to categorize digital images of words. A wide variance in letter spacing, along with print, italic and script font styles, which provide a variety in shapes, combine into a large vocabulary. Using this vocabulary, this research determines whether or not a reading machine can be based on low order Fourier Transforms. Therefore, this research has developed an algorithm for a reading machine which is:

1. capable of reading a large vocabulary of words and numbers without having to segment the individual characters; therefore, it will identify text as whole words or complete numbers.
2. capable of reading printed and cursive font styles.
3. scale invariant and substantially insensitive to noise.

II. Background

This portion will include the psychology of reading, the Fourier transformation used to model the gestalt theory, and my masters thesis. The first discussion centers on the psychology behind reading.

2.1 Physical parts

In modeling the reading process, it is important to overview the physical components of the system. Light focused on the human retina generates electrical signals that code the pattern content. The signals, in the form of pulses, transmit along the optical nerve to the thalamus so that a topological mapping of the viewed image exists both at the lateral geniculate in the thalamus and subsequently at the visual input cortex. The original image and the image presented at the visual input cortex maintains a homeomorphic (one-to-one correspondance) relationship. See Figure 2 for a drawing of the human visual system. But from this point, mapping is lost by the vast interconnectivity between the input cortex and the visual association cortex. It is postulated, that at this point, what is commonly known as the gestalt process probably occurs. (12:260) The interconnections between the visual input cortex and the visual association cortex provide a mechanism through which an image is associated with a similarly stored or learned pattern.

2.2 Gestalt

The gestalt theory was originally developed in Germany to articulate what is known today as the interactions between the visual input cortex and the visual association cortex. It attempts to explain how one recognizes the world around him based on associations with what he has previously seen. "In German the word *gestalt* may be used as a synonym for *form*, or perhaps *shapc*. In *gestalt theorie* the word *gestalt* means any segregated whole." (9:192) The theory, first proposed in Germany about a century ago, describes how images are recognized by categorizing or segmenting them into individual parts and then reinforcing or inhibiting their association with memorized patterns. Recognition is not necessarily based on a single simple association but on a countless number of associ-

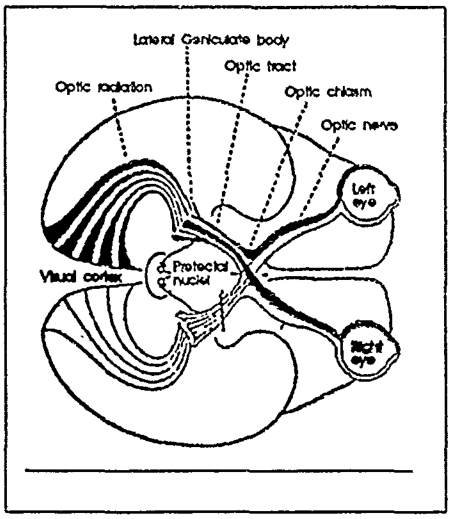


Figure 2. The Human Visual System
(5:626)

ations. (8:1128) All of this is theorized to occur in the vast interconnections within the brain. Other than image content, many other factors affect what the brain perceives, note Figure 3.

"The number *4* is certainly well known, but without prior instructions or warning, only a few people would include it in the description of Figure 3. Now look at Figure 4 and the *4* would probably be included in most persons' description of the figure. Why, then, is it seen now? Because the relation between the added lines and the geometrical parts of the *4* are not such that these parts are absorbed in the formation of the wholes." (9:209) The brain is continually segmenting an image into parts that then are considered as *wholes.* Therefore, the way in which an image is perceived is based on how the image is segmented.

This continual segmenting into wholes occurs everytime one looks at an image. Depending on what prior instructions one is given, (ie. reading, looking for one's keys, etc.) he associates the segments with memorized patterns (there's a *4*, here's the keys, etc.). So when reading, it is theorized the brain preprocesses what it sees with a predefined list of acceptable symbols or segments. Therefore, for reading, gestalt is how one associates text to what is stored in the memory based on similar shapes. To understand how one might model this association, one should look closely at the reading process itself. (9:3)

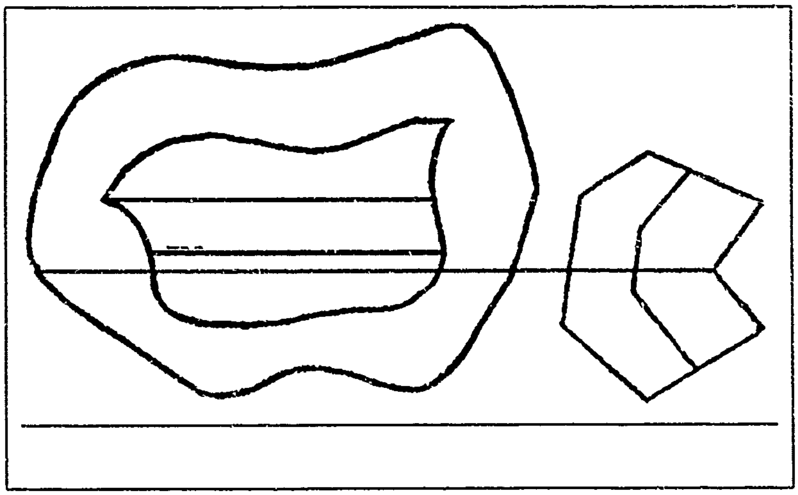


Figure 3. The Hidden Four

(9:200)

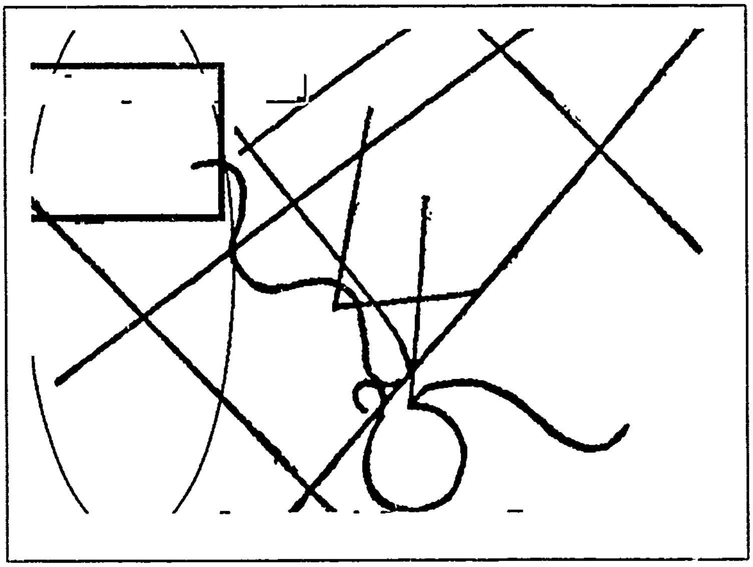


Figure 4. The Obvious Four

(9:210)

2.3 Reading Process

The first question should be: *What is reading?* Some might believe reading is simply seeing what is printed on a page, but reading also includes comprehension, creative thought, and auditory sounds. Words are merely symbols which serve to recall a particular meaning or idea. There is no physical relationship between the word *lion* and the actual animal, yet the image of the word is used as a symbol to represent a physical object. What about the word *very*? It is not a tangible object yet it is a symbol used to convey a meaning and develop comprehension. How the brain associates a symbol to previously known symbols is considered recognition for this discussion. How the brain relates these symbols after they are recognized is considered comprehension. It is important to note that the two are not mutually exclusive in the brain. They both provide recursive information to one another during reading.

Tinker theorizes that the simple mechanics of reading begins with breaking down sentences into specific windows. The eye moves along a string of words making frequent stops or fixation pauses. The actual reading or recognition process occurs at the pauses. These pauses on the average are about 250ms. (16:12) Figure 5 is an example of this. Figure 5a is the eye movements of a good adult reader and Figure 5b is the eye movements of a poor adult reader. Between pauses no recognition occurs. The eyes are continually fixating, sweeping, fixating, sweeping.

During the fixation phase a person perceives a word or phrase. Research shows that the perceptual span for adults is 3 to 4 unrelated letters during this phase. When letters are grouped in the form of nonsense syllables (combination of letters that can be pronounced but which do not make a meaningful word, as *bak* or *snerk*), the perceptual span increases to about 7 letters. As the meaning becomes clearer, the perceptual span increases. (16:14)

In 1898, R. Doge and B. Erdmann proposed and supported the view that proficient readers perceive printed material in either units, whole words, or entire phrases. Their results showed test subjects "recognized words that were printed in type too small for individual letters to be identified; too far in peripheral for recognition of their component letters; and exposed beyond the distance at which individual letters could be recog-

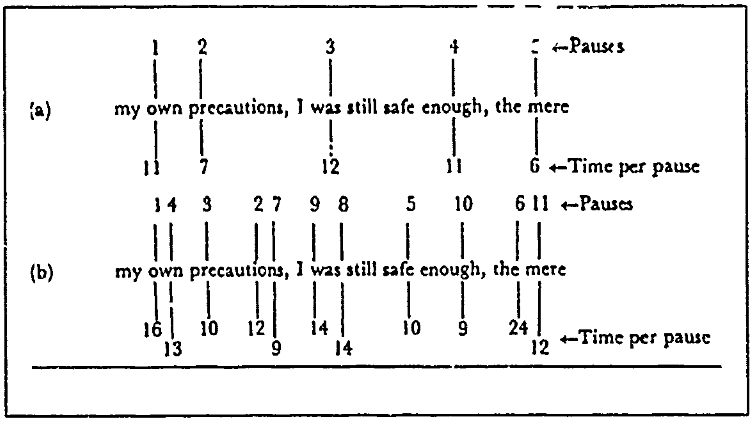

1 2 3 4 5 ←Pauses
(a)
my own precautions, I was still safe enough, the mere
11 7 12 11 6 ←Time per pause
1 4 3 2 7 9 8 5 10 6 11 ←Pauses
(b)
my own precautions, I was still safe enough, the mere
16 13 10 12 9 14 14 10 9 24 12 ←Time per pause

Figure 5. Location of Fixation Pauses

(16:61)

nized." (16:15) As a result, "the arrangement, the total form, is the main thing, whether in the recognition of letters, numbers, words, of objects of whatever sort". (16:15)

In a later test by Koffka, "a word of 25 letters tachistoscopically exposed letters (i.e., flashed briefly on a screen) can be seen clearly and distinctly in all its parts, ... whereas with 25 unconnected letters at ' st a small fraction will be perceived." (7:592) Tinker therefore concludes, "the fact that during - -eading fixation pause a person may at times read in a sentence words containing 20 to 30 letters with a typical average of 8 to 10 letters, but can perceive only 3 to 4 unrelated letters, suggests that in reading, perception must take place by some means other than the recognition of individual letter after letter." (16:14)

When unfamiliar words appear, the brain can only perceive them by a process of analysis. This process involves limiting the window, or number of letters to be perceived, by breaking the word into small components. The amount of analysis depends on the degree of unfamiliarity. Words previously recognized by the brain may have a wide range of familiarity. Familiarity increases with each reoccurrence of the word. Therefore, the mechanics of reading is to portion the input into segmented wholes for further processing.

Next one must look at the components of reading. Recall the visual system is not the only input to reading. The visual system, the auditory system, and the intellect (comprehension and creative thought) are all components to reading. Each facet of reading provides an input of sorts, which allows a person to recognize the segmented wholes.

Text consists basically of organized scribblings. These scribblings have distinct rules according to their shapes. They include vertical, horizontal, diagonal, and curved lines. (16) All letters are distinguished by their parts. The letter *c* is a round or curved line opened on the right; the letter *l* is a single vertical line, etc. Gibson and Levin claim the cognitive process has established a distinct rule based system that makes up these scribblings to create a standard between symbols. (4)

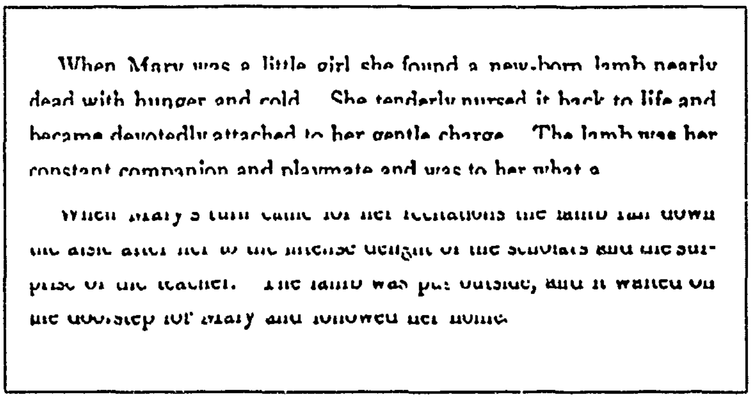
This rule system includes character segmentation. The location of space bounds our symbols. Improper spacing creates confusion and ambiguity concerning which symbols are to be grouped into words. Compare the two phrases:

- *the red earrings you race*
- *there dear rings your ace*

Both have the same set of characters in them yet with different segmentations. Proper segmentation between words as well as proper segmentation within words is important. Compare *lousy* with *busy*. It is very important to distinguish between the two when telling one's boss how work is proceeding.

Not only is there information contained between symbols, but certain parts of symbols seem to carry more importance than others. Take for example Figure 6. There is a unique difference in a reader's ability to read the top from the bottom half of words. This difference is incorporated in the brains ability to segment and provide the most meaningful data to the area where association occurs.

Huey noted that "a preponderance of distinctive features exists in the tops of the letters." (4:170) In addition to this, the brain has learned an orthographic rule system. These rules "govern what sequence of letters and groups of letters may be put together to form words. Everyone knows that the letter *q* is followed by *u* and that the cluster of the two letters is pronounced /kw/. The cluster km is not permitted, unless it crosses a morpheme boundary: milkmaid." (4:173) The orthographic rule system is a preprocessor when reading.



When Mary was a little girl she found a new-born lamb nearly dead with hunger and cold. She tenderly nursed it back to life and became devotedly attached to her gentle charge. The lamb was her constant companion and playmate and was to her what a

When Mary's turn came for her recitations the lamb ran down the aisle after her to the intense delight of the scholars and the surprise of the teacher. The lamb was put outside, and it waited on the doorstep for Mary and followed her home.

Figure 6. Visual Importance of Top and Bottom Half of Words (4:171)

So the human visual system has a learned set of rules to segment text when reading. Proficient readers make fewer pauses and errors when reading and can associate longer words in a single pause than poor readers. (8) In reading, the ability of properly segmenting words is a learned response. The brain naturally segments any image it sees, but proper letter segmentation based on a learned rule system is vital to good reading skills.

For the purpose of discussion, the second input source is called the auditory track. "Correctly pronouncing a word ordinarily recalls its meaning if it is in the reader's speaking vocabulary. Coordination of the visual and auditory aspects of phonics is essential." (16:34) While reading silently, most readers internally verbalize what they see. Therefore, phonics plays an important part in recognition and can be considered as a secondary input. Table 7 displays an analysis of word features. The table analyzes "the proportional use made of eight different word features in the preferred word-recognition strategies of children and adults and was conducted by Selvin Chin-Chance of the University of Hawaii. The eight objective measures of word similarity, identified at the bottom included semantic features, phonetic features and meaning along with visual features for a set of 24 carefully chosen words. In addition the eight objective measures of word similarity were correlated with each subject's own subjective estimated of word similarity. The results of this experiment showed that whereas phonetic cues are popular among children, particularly third-graders, they are not used extensively by adults, perhaps because sounding out the word is too slow

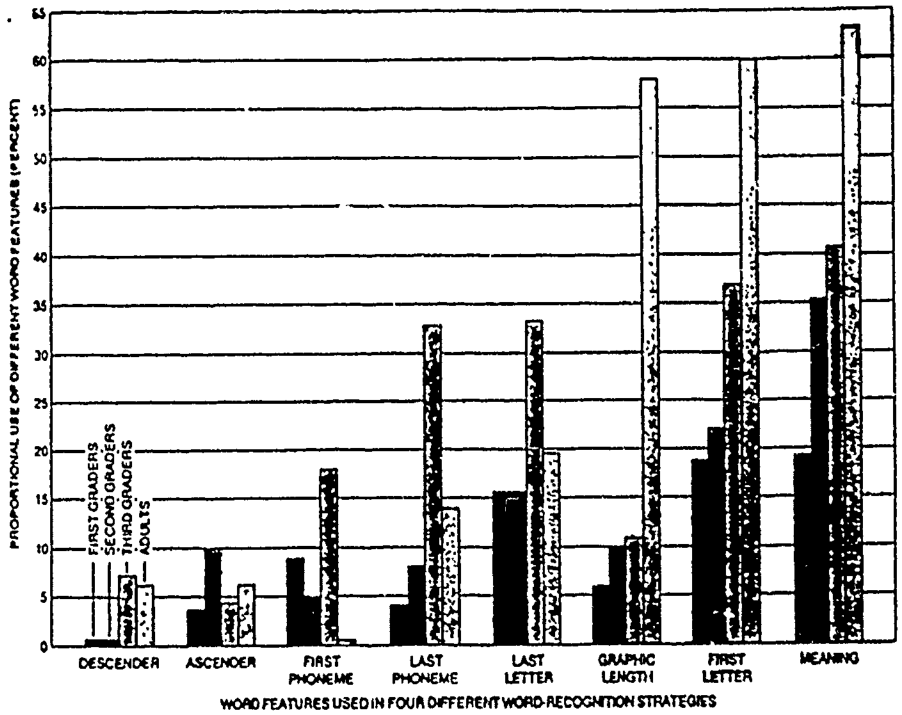


Figure 7. Eight Measures of Word Similarity

(3:129)

a process for an efficient recognition strategy." (3:129)

The bottom line is this: auditory input plays a varying role in the brain's ability to recognize a word. Dependence upon vocalization increases in childhood and drops off by adulthood. This is probably because the brain visually recognizes a word as opposed to vocally sounding it out. It is important to note that most adults retain this source of input to some extent.

The last group on the graph points to the third and final input source: syntactic rule structure (the meaning of the word). This deals with the grammar, which is defined by Lindemann as "a capacity for language, a native ability to create and comprehend English utterances." (11:107) This rule structure concerns the comprehension and creative thought aspect alluded to earlier in this discussion. Sentence structure and meaning have a tremendous influence on recognition speed. A sample group of forth graders took a simple

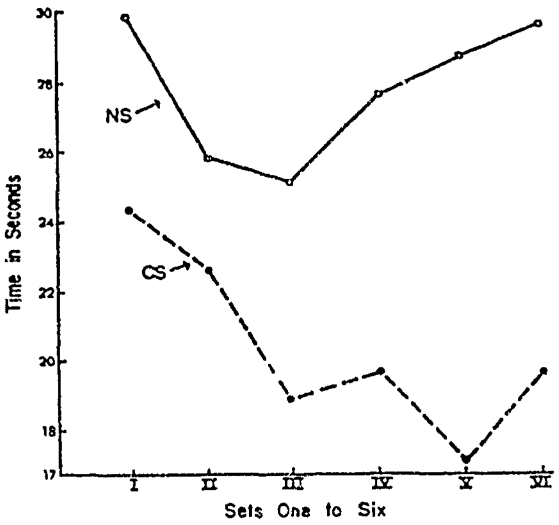


Figure 8. Anagram Testing of Forth Graders
(4:55)

anagram (discovering a word in a set of jumbled letters) test to prove this point.

The test involved solving anagrams that were arranged into six categories (Figure 8). The categories were fruit, drinks, animals, utensils, colors, and furniture. The two conditions, CS and NS, were arranged so that they did or did not, respectively, yield an ordered set when completed. The results show that if subjects expected to fit the anagram into a specific group, it greatly increased the speed with which the anagram was solved. However, solving them at random showed a decrease in problem solving speed. Therefore, given speed of identification as a measure of recognition, *apriori* knowledge of the meaning, category, etc., the brain's ability to recognize a particular image will increase significantly. Hence, one can note the relationship between visual recognition and intellect.

2.4 Fourier Transform

Some aspects of what the cerebral cortex does through a vast array of interconnections, can be modeled mathematically by the Fourier transform. Radoy (14) and later Tallman (15) have defined the 2DFT algorithm for use with a real input image array. The algorithm is not dependent on powers of 2 as in the case of a fast Fourier transform. Kabrisky (6) and later Maher (12) have used this algorithm to show a degree of relationship between machine and human outputs. Maher's analysis "involved discriminating 10 animal forms by computer simulation and by a group of 46 individuals." A Pearson correlation coefficient of 0.961, between machine and human responses, was calculated. The results, therefore, supported the use of 2DFT coefficients as an image recognizer. (12:260)

Bush (1) applied this algorithm to the 26 letters of the alphabet. He used the image of the letters of the alphabet as his input. His desire was to develop a more legible set of characters. His thesis, like Maher's work, supported the algorithm of 2DFT's by using psychological testing to verify machine results. His work used five separate font types and opened the way for character identification based on 2DFT coefficients.

The problem with this identification scheme, however, is that segmentation of the text into individual characters is required; isolated characters do not usually occur in printed text. It suffices to say, years of research spent on letter segmentation has produced little, if any, success With the appearance of phototype setting and laser printers, the segmentation problem has increased. Recall that gestalt assumes segregated wholes within an image. The algorithm works to model the vast interconnections between the primary input cortex and the visual association cortex, but it begs the questions concerning segmentation.

In my earlier thesis (13), I postulated that text segmentation can be achieved by using the whole word. The spacing between ords is easy to locate, but the spacing within words is unobtainable. It is evident that the brain handles words as wholes; what hinders the algorithm from handling it the same way? This was the approach taken in my thesis work and the results were promising.

The tests included the top 200 most popular words in the English language in capital form. The same font styles used in Bush's thesis were used in my earlier thesis. Spacing between letters within a word were fixed. Overall recognition of a particular word in one font style proved 94% successful in chosing the same word in a different font style than a different word in either the same or different font style. Word similarity was almost independent of font type.

Though a very limited test, the algorithm did prove the hypothesis: word recognition based on 2DFT's can be achieved by treating the image of a word as a single segmented whole. For use as a reading machine, proof that a full scale machine can be developed is required. The need for thousands of words, in many font types, with variable letter spacing, and lower case letters must be shown. These variables increase the search space or choices from this previous work by many orders of magnitude.

III. Methodology

3.1 Overview of Process

The approach to solving the problem concentrated on generating digital images of words, computing the 2DFT of each image, and then selecting nearest neighbors (minimum error calculation) based on the differences in coefficient values. This seems simple enough, but a few obstacles need a solution. Building the font base is the first step. To provide maximum flexibility, the particular font styles are digitized and then the images of words are built from the digitized font styles. This allowed for spacing between characters to be varied and greatly decreased the disk storage space. Selecting how to compute the error or difference calculations (nearest neighbor) between coefficients is the second step. The key to separating similar words in different fonts is in the method used for distance calculation.

Following the basic methodology outlined above, specific variations are covered in Chapter 4. The variations are presented in Chapter 4 because their selection or deletion is based on interim results and logical conclusions or exclusions. Therefore, the beginning step is to build the digitized font styles.

3.2 Building Fonts

A professional printer (2) selected 25 font styles to provide depth and diversification between font styles. Popularity, then variation, are the priorities for font selection. The most popular font styles (Avant Garde, Zapf Chancery, Garamound, Megaron, and Schoolbook) are provided in a variety of styles. The styles include light, medium, bold, and italicized prints. The printer chose these fonts because they are widely used and popular

The printer also chose Eurostile, Gill Kayo, Hobo, Janson, and Wedding Text for their variation in style. These font styles range from plain to ornate in style and provide variation from the more popular fonts. Also selected for variation is Brush and Helena Script, which are two script (cursive) fonts. They are included to test whether or not cursive text can also be identified using the same algorithm. The complete list of fonts used is listed in Table 1.

Table 1. Font Styles

Avant Garde
Avant Garde bold
Brush
Zapf Chancery light
Zapf Chancery light italicized
Zapf Chancery medium
Zapf Chancery medium italicized
Eurostile
Eurostile bold
Garamound bold
Garamound bold italicized
Garamound italicized
Gill Kayo
Helena Script
Hobo
Janson
Megaron bold
Megaron bold italicized
Megaron medium
Megaron medium italicized
Schoolbook
Schoolbook bold
Schoolbook bold italicized
Schoolbook italicized
Wedding Text

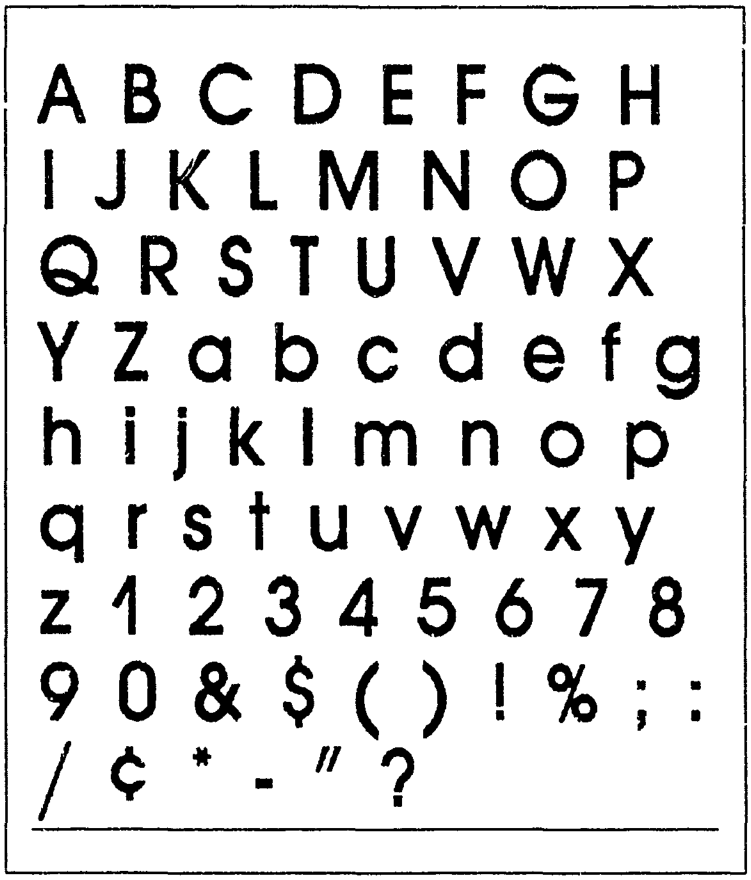


Figure 9. Avant Garde Font Style

An example of a complete font style is shown in Figure 9 with the remaining 24 font styles presented in Appendix A.

Each font style in Appendix A is digitized into a 480 x 510 pixel field. The digitized picture is searched to locate individual symbols and then store each symbol separately. The program catalogues each symbol by windowing, allowing no space around each symbol. Once the symbol is cataloged, a left and right margin offset is added. This offset represents a shift along the horizontal axis to be used at the time of printing. The reason for this offset is because typesetters do not print with fixed distances between symbols. They give narrower symbols, like *i* and *l*, more spacing as opposed to wider symbols, like *m* and *s*. Italicized styles use this offset distances to bring vertical lines closer together, as in *fl* and *fy*. The result is that each font style is digitized, and each symbol is individually stored with its own local offset values. An example of how an individual symbol is digitized and stored onto disk is the letter *f* from the font style *Zapf Chancery medium italicized.* It is shown in Table 2.

3.3 Building Coefficients

Appendix C shows a list of the 5000 most popular words in the English language. The list is not alphabetized, but it is in order of occurrence with *the* being the most popular. The list is taken from 500 articles within a field of 15 areas (press, religion, scientific writing, fiction, etc.). One million words were used to compute occurrences. (10) To make it possible to vary the overall spacing between symbols within a word, an additional offset value is added to each symbol's individual offset value. The spacing between characters varied f^rom -7 to +9 pixels. Excluding left and right margin values, the average symbol width is 16 pixels. Thus, it is possible to vary spacing within a word from between -45% to +55%. An example of the spacing variance is shown in Figure 10.

Once a word is built using a particular font style with a particular offset, the image array is Fourier transformed using Radoy's algorithm. (14) The method for performing the 2DFT are as follows. The image of a word is formed from an M x N matrix that has a single grey level value, 0 (white) and 1 (black), recall Table 2. The image is completely described by the real valued function, f(x,y), which is defined only at the coordinate points at which x and y are both integers. See Equation 1.

$$F(A,B) = \sum_{j}\sum_{k} f(x,y) \cdot [\cos(A \cdot x + B \cdot y) + i \cdot \sin(A \cdot x + B \cdot y)] \qquad (1)$$

where,

- A $= j \cdot 2 \cdot \pi \div M$
- B $= k \cdot 2 \cdot \pi \div N$
- i $= \sqrt{-1}$
- j = -5, -4, ..., 0, 1, ..., 5 order of harmonics in x direction

Table 2. An Example of a Digitized Character

where:

a = symbol identification

b = height in pixels

c = width in pixels

d = distance (above or below) baseline

e = left margin indent

f = right margin indent

0 ≡ white space (pixel)

1 ≡ black space (pixel)

```
a b  c   d  e f
f 46 23 -12 4 3
00000000000000000011111
00000000000000000111111
00000000000000001111110
00000000000000011100000
00000000000000111000000
00000000000000111000000
00000000000001110000000
00000000000001110000000
00000000000001110000000
00000000000011110000000
00000000000011110000000
00000000000011100000000
00000000000011100000000
00000000000011100000000
00000000000111100000000
00000001111111111111000
00000011111111111110000
00000111111111111100000
00000000001111000000000
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00000000110000000000000
00000001110000000000000
00000001110000000000000
00000001100000000000000
00000001100000000000000
00000011100000000000000
00000111000000000000000
00111110000000000000000
11111100000000000000000
11111000000000000000000
11110000000000000000000
```
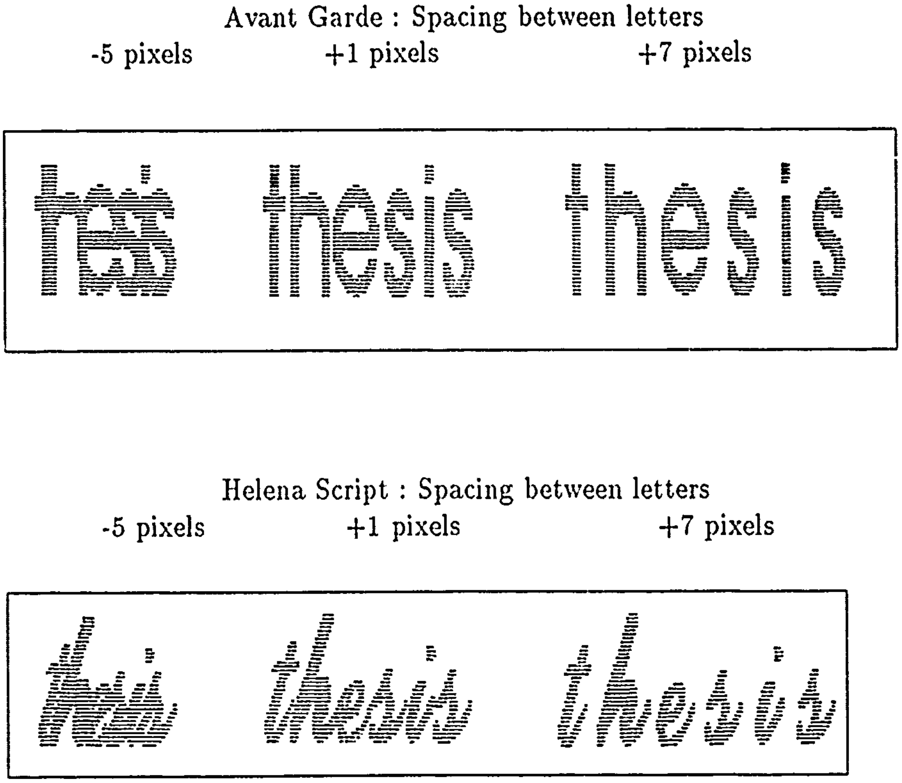



Avant Garde : Spacing between letters

-5 pixels +1 pixels +7 pixels

Helena Script : Spacing between letters

-5 pixels +1 pixels +7 pixels

Figure 10. Actual Images with Varied Spacings

- k = -5, -4, . . . , 0, 1, . . . , 5 order of harmonics in y direction
- M = height of image in pixels
- N = length of image in pixels
- x,y = location of real valued input
- f(x,y) = intensity of image at location x,y

The two equations that define the real, Re[F(A,B)], and imaginary, Im[F(A,B)], Fourier components are,

$$Re[F(A,B)] = \sum\sum f(x,y) \cdot \cos(A \cdot x + B \cdot y) \tag{2}$$

$$Im[F(A,B)] = \sum\sum f(x,y) \cdot \sin(A \cdot x + B \cdot y) \tag{3}$$

Since the cosine is an even function and the sine is an odd function, the following relationship exists in equations 4, 5, 6, and 7. (14)

$$Re[F(A,B)] = Re[F(-A,-B)] \tag{4}$$

$$Re[F(-A,B)] = Re[F(A,-B)] \tag{5}$$

$$Im[F(A,B)] = -Im[F(-A,-B)] \tag{6}$$

$$Im[F(-A,B)] = -Im[F(A,-B)] \tag{7}$$

Therefore, due to the symmetric properties of the Fourier transform, only half the cosine and sine terms are unique and need be calculated at any one time. For an example, a 5 x 5 harmonic space has 11 (-5 to +5) vertical harmonic terms times 11 (-5 to +5) horizontal harmonic terms producing 121 cosine and 121 sine terms. Since half the terms are duplicated due to symmetry, there exist 61 unique cosine and 60 unique sine coefficients (note the dc term for the sine function is always equal to zero). For the case of 2 x 4, two vertical and four horizontal harmonics, there are 5 (-2 to +2) vertical terms times 9 (-4 to +4) horizontal terms giving a total of 45 unique coefficients.

The coefficient values for each word displayed in each font style with one particular offset spacing are stored for the 5 x 5 case. Before they are stored though, they are energy normalized. The normalization process accounts for brightness variations and is equivalent to graphing each 2DFT onto the surface of an n-dimensional hypersphere with unit radius ($r = 1.0$). Equation 8 is used to normalize the coefficients.

$$\overline{F}_{r,c} = \frac{F_{r,c}}{[\sum_{r=1}^{2n+1} \sum_{c=1}^{2n+1} F_{r,c}^2]^{1/2}} \quad (8)$$

where,

- $\overline{F}_{r,c}$ = the normalized (r,c)'th element
- r = rows
- c = columns
- n = number of harmonics

Therefore, the program to compute the 2DFT coefficients, builds the words from the individually digitized font characters, calculates the 2DFT coefficient values, and stores the values on disk.

To vary from computing the 2DFT of an entire word, one strategy is to break the image of a word into three equal parts and then to compute the 2DFT of each part. The reason for doing this is discussed in the Chapter 4, but the approach is identical for the entire word process. The only difference is that the three subparts are used as inputs to the 2DFT distance calculations.

3.4 Distances

Once the coefficients are computed, the difference calculations are made. This is known as 'finding the nearest neighbor' or minimizing the error. Each image is represented by a set of coefficients, which in turn represents a single location on the n-dimensional hypersphere. For this case of 121 coefficients, n equals 121. If a subset of coefficients is used then n would equate to the number of coefficients being used to define the image of a

Table 3. Distance Equations

name	*equation*
H2	$d_{x,y} = [\sum_{i=1}^{n}(x_i - y_i)^{1/2}]^{1/2}$
H1	$d_{x,y} = [\sum_{i=1}^{n}(x_i - y_i)^{1/2}]^{2}$
M1	$d_{x,y} = \sum_{i=1}^{n}(x_i - y_i)$
M2	$d_{x,y} = [\sum_{i=1}^{n}(x_i - y_i)^{2}]^{1/2}$
M3	$d_{x,y} = [\sum_{i=1}^{n}(x_i - y_i)^{3}]^{1/3}$

word. The nearest neighbor is defined as the pair, input word to output (template) word, with the minimum error. This test used five equations of distance or error calculations. They were selected from previous works but are not the only choices available. They are listed in Table 3.

3.5 Font Groups

In my thesis (13), I compared each word with all other words in all font styles, using only the M2 (euclidean) distance measurement. The top 1000 words in 25 fonts gives a total of 25,000 (1000 x 25) words images. Therefore, each word would be compared to 24,999 words (any word compared to itself would yield an error of 0.0). If 10,000 words are used, then the search space is 249,999 words. Computationally, this is too time consuming. A way of limiting the search space and increasing successful matches is needed. Combining font styles into font groups is one approach. Since coefficients are orthogonal, each Fourier coefficient of a particular word can be averaged with the coefficients from the same word spelled in different font styles. The intent is to create a generic font style in Fourier space made up of different and unique font styles. These generic font styles are called *font groups* and can be thought of as an average between font styles.

Three programs were developed to create font groups. The first one uses all 25 font styles and averages each coefficient for each of the top 1000 words. By creating a single font group from the 25 font styles, there are only 1000 target (template) words instead of 24,999. The second program divides the 25 font styles into three separate font groups. The division into three font groups is listed in Table 4. The result is then 3000 (3 font group x

1000 words) target words.

And finally, the third program divided font groups up by placing similar looking font styles into six groups. To obtain six groups, the *regular* font group from 3 font three font case is subdivided into three subgroups and one more font group, *special*, is added. The letters *a* and *g* are the criterion for subdividing the *regular* font group into subgroups. They were chosen because their visual shapes, (a,*a*) and (g,*g*), seemed to have the greatest variation between font styles. The division into font groups is listed in Table 5. It will yield 6000 (6 font groups x 1000 words) target words.

3.6 Special Cases

This research develops three additional distance calculations. The first is the 3 part coefficient values. The objective is to compute the five nearest neighbors for any word and then from this partial nearest neighbors list, recompute a final choice based on the 2DFT images of the first, middle, and last parts of the word. By concentrating on this partial list, a second pass is made using an alternate distance calculation, to pick the correct choice. It uses four sets of calculated coefficient values; one from the entire image of a word and one from each of the first, middle, and last parts of a word. It is done only for the 3 font group case.

The second special case involves an approach to fine tune the font groups. The idea is that through a special transform developed for each font style, the mean errors (differences) can be reduced. This algorithm pushes a font style in Fourier space toward a particular font group. When reading an unfamiliar font style, the brain reads at a slower rate. I hypothesize that the brain is comparing the new font style to what it already knows. Given enough time, it composes a transform for that particular font style. Then, when enough training is incurred, the new font style is assimilated into the brain's working data base of font styles.

The transform develops by taking a subset of the input words (i.e., the first 200 of the top 1000 words) and averaging the individual coefficient errors between input word and nearest neighbor. These averaged coefficient errors are then subtracted from the font

Table 4. Font Styles for 3 Font Group Case

font group name	*font style*
italics	Zapf Chancery light
	Zapf Chancery light italicized
	Zapf Chancery medium
	Zapf Chancery medium italicized
	Garamound bold italicized
	Garamound italicized
regular	Avant Garde
	Avant Garde bold
	Eurostile
	Eurostile bold
	Garamound bold
	Hobo
	Janson
	Megaron bold
	Megaron bold italicized
	Megaron medium
	Megaron medium italicized
	Schoolbook
	Schoolbook bold
	Schoolbook bold italicized
	Schoolbook italicized
script	Brush
	Helena Script
†	Gill Kayo
	Wedding Text

† = *not used in any font group*

Table 5. Font Styles for 6 Font Group Case

font group name	*font style*
italics	Zapf Chancery light Zapf Chancery light italicized Zapf Chancery medium Zapf Chancery medium italicized Garamound bold italicized Garamound italicized
regular a	Avant Garde Avant Garde bold Schoolbook bold italicized Schoolbook italicized
regular *a* g	Eurostile Eurostile bold Megaron bold Megaron bold italicized Megaron medium Megaron medium italicized
regular *a g*	Garamound bold Janson Schoolbook Schoolbook bold
script	Brush Helena Script
special	Gill Kayo Hobo
†	Wedding Text

† = *not used in any font group*

group(s). A final pass is made for all 1000 words and the nearest neighbors recalculated. Each font group selected in the first pass needs an error transform. The underlying idea is that apart from any particular symbol within a font style, each font group and font style as a whole has its own characteristic shape or form. The average of coefficient errors is a map of the difference or error in characteristic shape and by adding the negative (inverse) to the font group, the distance to the nearest neighbor is then reduced. Thus, reducing the distance should reinforce the correct choice. This program is presented in Appendix B. A special note about this program is that if a correlation does not exist between the characteristic shape of a font style and a font group, then the values of the coefficient errors will be random and their averaging will generate a zero response.

The third special case uses redundancy to eliminate incorrect choices. In the field of the 5 x 5 coefficients, it is possible to select any or all of the coefficients as a search space. The advantage to this is that a selection based on a different set of coefficient values yields different incorrect choices. If the incorrect choices occur only 1 to 2 percent of the time, then with 3 separate sets of coefficients it will be possible to form a weighting scheme. If choice occurs in 2 out of the 3 sets then the most popular choice is taken.

Overlapping of sets is useful only if the incorrect choices are different. The appropriate coefficients to use in a given set are determined empirically (trial and error). Each set is energy normalized based on the number of coefficients within the set. Therefore, the actual value of the distances between sets to the nearest neighbor might not be a useful measure. Only the target word (nearest neighbor) is of primary concern.

IV. Results

The results are divided into three sections. Thr first section is the extension of my Master's thesis research into a much larger search space, with lower case letters. The second section presents the font groups, which are the heart of a true reading machine and comprises the bulk of the chapter. The third section covers the special distance calculations.

4.1 Originals

Comparing each font style to itself and all other fonts is the first case presented. The M1 (taxi) distance calc ılation (see Table 3) is used to compute the nearest neighbor (minimum distance to adjacent image in Fourier n space) for each of 25,000 input words (1000 words in 25 font styles). Given that there are 25,000 inputs, then there are 24,999 possible nearest neighbors for each input image. With the internal letter spacing (offset value) within a word set to +3 pixels (letters have an average width of 16 pixels), the percent of correct choices using a 3 x 3 harmonic search space is listed in Table 6. This table shows how effective the algorithm is at identifying a correct match (input word and nearest neighbor are the same word) for the most popular 1000 words in each of the separate 25 font styles.

Each font style is listed with the percent correct, its mean distance to nearest neighbor (using M1 distance calculation), and the standard deviation of nearest neighbors. The algorithm in my Masters thesis produced 94% correct choices for 200 capitalized words in 6 various font styles. (13) It is evident from Table 6 that the script fonts (Brush and Helena Script) do not work and the fonts selected for their variation in style (Eurostile, Gill Kayo, Hobo, Janson, and Wedding Text) are marginal at best. If we are to jump to 10,000 words at this point, the percent correct would be too low to build a reading machine based on this algorithm. Also, the computational time for this 1000 word case required 24 cpu hours on a sun4 (12 mips) processor. It would be 10^2 as long, 100 cpu days, for 10,000 words. Even though this algorithm can identify words without letter segmentation, it still is not realistic to use this approach because the percent correct is too low and the computation time too long.

Table 6. Distances for Originals With a +3 Spacing

Font Style	% correct	mean dist between nearest neighbors	standard deviation between nearest neighbors
Avant Garde	84.2	0.77	0.22
Avant Garde bold	87.3	0.56	0.18
Brush	16.5	1.03	0.29
Zapf Chancery lght	89.6	0.83	0.21
Zapf Chancery lght ital	93.1	0.67	0.23
Zapf Chancery med	88.7	0.75	0.18
Zapf Chancery med ital	94.2	0.65	0.21
Eurostile	84.5	0.88	0.24
Eurostile bold	85.0	0.65	0.15
Garamound bold	88.2	0.75	0.17
Garamound bold ital	95.5	0.61	0.17
Garamound ital	97.6	0.62	0.17
Gill Kayo	42.0	0.73	0.18
Helena Script	7.8	1.00	0.33
Hobo	57.6	0.72	0.21
Janson	88.0	0.77	0.17
Megaron bold	97.0	0.51	0.13
Megaron bold ital	91.4	0.57	0.18
Megaron med	96.6	0.63	0.15
Megaron med ital	94.0	0.68	0.20
Schoolbook	95.7	0.64	0.13
Schoolbook bold	96.1	0.64	0.13
Schoolbook bold ital	98.1	0.53	0.13
Schoolbook ital	98.4	0.53	0.13
Wedding Text	49.2	0.84	0.27
overall % correct	80.6	0.70	0.19

Selecting a different spacing does little to change performance. Table 7 presents the results of the case where letter spacing within words is increased from +3 to +7 pixels. The overall percent correct increased to only 81.9%, and percentages for specific fonts did not vary greatly. The overall mean distance between an input word and its nearest neighbor decreased only by about 0.02 and the overall standard deviation decreased by only 0.01. This is significant because the mean and standard deviation are indicators of performance. As the mean decreases (assuming a constant number of coefficient values) for any font style, the percent correct increases. Some correlation exists between the mean and standard deviation of nearest neighbors and the percentage of correct choices for font styles. A font style with higher mean and standard deviation values than a second font indicates the first font will have a higher error rate (i.e., lower percent correct). This can also be seen in the results presented in Table 7.

Creating font groups is the answer to increasing the percent correct while decreasing the computational time (search space). In the next subsection, the results of creating font groups and the variables affecting their use are presented.

4.2 Font Groups

There are many variables and questions to be answered concerning font groups. When dealing with a particular variable, all other variables will be fixed. A standard spacing of +3 pixels is used unless noted, not because it is superior to all spacings, but because it is a visually comfortable spacing and is a nominal value between the extremes of -7 and +9 pixels. The variables to be covered are:

1. how are font groups best divided and how many should there be
2. which is the best distance rule to use
3. what is the affect of spacing between letters in a word
4. what is the optimum number of Fourier harmonics to use
5. is word length an important discriminator
6. how many words are possible
7. how does script font compare to printed font

Table 7. Distances for Originals +7 Spacing

Font Style	% correct	mean dist between nearest neighbors	standard deviation between nearest neighbors
Avant Garde	84.9	0.75	0.22
Avant Garde bold	90.5	0.55	0.17
Brush	22.7	1.03	0.28
Zapf Chancery lght	89.8	0.80	0.20
Zapf Chancery lght ital	93.3	0.64	0.22
Zapf Chancery med	90.2	0.71	0.17
Zapf Chancery med ital	94.5	0.63	0.20
Eurostile	85.9	0.86	0.23
Eurostile bold	86.2	0.64	0.15
Garamound bold	88.8	0.72	0.16
Garamound bold ital	96.1	0.59	0.17
Garamound ital	97.1	0.59	0.16
Gill Kayo	47.4	0.75	0.18
Helena Script	9.5	1.01	0.33
Hobo	57.7	0.71	0.21
Janson	89.5	0.75	0.17
Megaron bold	97.2	0.49	0.12
Megaron bold ital	92.3	0.54	0.17
Megaron med	96.1	0.61	0.15
Megaron med ital	95.0	0.65	0.19
Schoolbook	95.2	0.63	0.13
Schoolbook bold	96.7	0.63	0.13
Schoolbook bold ital	97.9	0.52	0.13
Schoolbook ital	98.5	0.52	0.13
Wedding Text	54.6	0.82	0.27
overall % correct	81.9	0.69	0.18

8. what happens when a new font style is encountered for the first time
9. what happens when a new spacing is encountered for the first time
10. how does noise affect the percent correct
11. what about upper case letters
12. what about using numbers

4.2.1 Dividing into Font Groups. In addition to the three font groups discussed in the methodology, two other groups are added. Because experience showed that the algorithm had a consistent problem in identifying the correct nearest neighbor for the Avant Garde font styles. It was hoped that alternate divisions to the 3 and 6 font groups would solve the problem. The alternate groups developed from this experience are the 4 and 7 font groups. Their break down into groups are listed in Tables 8 and 9, respectively.

A combined table of the results of the 1, 3, 4, 6, and 7 font groups, using the 3 x 3 harmonic space, a +3 letter spacing, the M1 distance calculation, and the top 1000 words is presented in Table 10.

The two most significant results are the overall percent correct of the 1 font group case versus the original algorithm, section 4.1, and the decrease in percent correct from the 6 font group to the 7 font group case. First, the 1 font group has an output space of 1000 words. The original case had an output space of 24,999 words. By combining the Fourier coefficients of the 25 different images of a word, to form a single font group, the overall percent correct from the original case to this combined case improved 6%. Consider how mixed the font styles are: printed, italicized, ornate, plain, and even script. All of these are different styles and yet combined they produce a better feature set than the individual font styles themselves, section 4.1. It begs the question: is there one generic font style that can recognize all font styles?

The answer to this seems to be no. The subsequent improvement in the 3, 4, etc. font group cases shows that one single font group is not optimum. The 1 font group case *is* a major breakthrough in reducing the search space of an algorithm's library of target words but is not the most accurate solution. From Table 10, a steady improvement is seen as the number of font groups increases. This increase occurs up until the 6 font group case and then decreases, which leads to the second significant finding.

Table 8. 4 Font Group Case

font group name	*font style*
italics	Zapf Chancery light Zapf Chancery light italicized Zapf Chancery medium Zapf Chancery medium italicized Garamound bold italicized Garamound italicized
regular a	Avant Garde Avant Garde bold Schoolbook bold italicized Schoolbook italicized
regular *a*	Eurostile Eurostile bold Garamound bold Hobo Janson Megaron bold Megaron bold italicized Megaron medium Megaron medium italicized Schoolbook Schoolbook bold
script	Brush Helena Script
†	Gill Kayo Wedding Text

† = *not used in any font group*

Table 9. 7 Font Group Case

font group name	*font style*
italics	Zapf Chancery light Zapf Chancery light italicized Zapf Chancery medium Zapf Chancery medium italicized Garamound bold italicized Garamound italicized
regular a	Schoolbook bold italicized Schoolbook italicized
regular *a* g	Eurostile Eurostile bold Megaron bold Megaron bold italicized Megaron medium Megaron medium italicized
regular *a g*	Garamound bold Janson Schoolbook Schoolbook bold
script	Brush Helena Script
special	Gill Kayo Hobo
avant	Avant Garde Avant Garde bold
†	Wedding Text

† = *not used in any font group*

Table 10. Comparison of Accuracy as a Function of the Number of Font Groups

	Number of Font Groups				
Font Style	1	3	4	6	7
Avant Garde	78.0	94.0	95.8	96.3	92.4
Avant Garde bold	91.9	97.6	98.4	98.1	93.2
Brush	43.4	97.3	97.3	97.3	97.3
Zapf Chancery lght	93.4	99.6	99.6	99.6	99.6
Zapf Chancery lght ital	90.9	99.8	99.8	99.8	99.8
Zapf Chancery med	94.8	99.9	99.9	99.9	99.9
Zapf Chancery med ital	92.0	99.9	99.9	99.9	99.9
Eurostile	90.8	98.3	98.7	99.6	99.6
Eurostile bold	97.7	99.9	100.0	100.0	100.0
Garamound bold	92.4	93.4	95.1	99.9	99.9
Garamound bold ital	94.2	99.3	99.4	99.4	99.4
Garamound ital	94.9	99.6	99.5	99.6	99.7
Gill Kayo	87.2	89.1	87.7	99.8	99.8
Helena Script	32.0	97.5	97.5	97.5	97.5
Hobo	62.1	65.3	65.4	93.3	93.5
Janson	92.4	96.9	97.6	100.0	100.0
Megaron bold	97.5	100.0	99.8	100.0	100.0
Megaron bold ital	96.6	99.4	99.5	99.9	99.7
Megaron med	89.5	98.7	99.1	100.0	100.0
Megaron med ital	93.5	99.4	99.1	99.7	99.7
Schoolbook	98.4	99.4	99.5	100.0	100.0
Schoolbook bold	98.8	99.5	99.6	100.0	100.0
Schoolbook bold ital	97.7	94.9	99.7	99.3	100.0
Schoolbook ital	98.7	96.9	99.7	99.4	100.0
Wedding Text	71.5	71.5	72.4	76.5	76.2
overall % correct	86.8	95.5	96.0	98.2	97.2
% correct excluding fonts not used in font groups	n/a	96.8	97.4	99.1	98.8

The decrease in overall percent correct between the 6 and 7 font group cases implies that, what makes a good font group is a good blend of similar font styles. This does not necessarily mean having a few, or a lot, of font styles within a font group. As font styles are grouped into similar groups, the mean distance between nearest neighbors gradually decreases until finally, in some cases, it rises. Groups possessing this decreasing distance are a good average between font styles. When the mean rises, font groups are becoming either too specialized (style dependent) or a poor mix of font styles. The best algorithm is not necessarily a function of how many font styles make up a font group but of the combined mix of font styles. Therefore, there is a tradeoff between having a generic font group that is a blend of font styles and the idea of becoming too font dependent or poorly mixing the font styles.

The ideal mix is still unknown. It seemed that the low performance of the Avant Garde styles could be solved by using 7 instead of 6 font groups, but obviously that is not true. When the Avant Garde, Avant Garde bold, Schoolbook bold, and Schoolbook bold italicized are put together into one font group, there is a 50% decrease of incorrect nearest neighbors than when the same four fonts are divided into two font groups with Avant Garde and Avant Garde bold in one group and Schoolbook bold and Schoolbook bold italicized in another. A well proportioned average makes a good font group. Dissimilar font styles will yield a font group which is not representative of the individual styles. In the 6 font group case the letters *a* and *g* are used as the discriminator between groups. The letter a appears two ways, in the form 'a' and '*a*'. The letter g appears two ways, in the form 'g' and '*g*'. But there is much more to a font's shape or style than just these two letters. That is why the decrease in percent correct from 6 to 7 font groups occurs when separating the font group into two font groups was thought to solve the low performance of the Avant Garde font styles. And since the algorithm using the 6 font group case is the best performer, it is used in determining the best measure of distance.

4.2.2 Distance Calculations. In the methodology, five distance calculations were discussed. H1, II2, and M3 were developed after M1 and M2 had been thoroughly tested. The M1 distance calculation is frequently termed 'taxi distance'. Envision the map of a large city where all roads run east-west and north-south. To travel from one point to another, the total distance traveled in the east-west direction is added to the total distance traveled in the north-south direction. Each trip from point A to point B is a simple problem of addition and subtraction.

For the case with M2, envision the same city, but a helicopter is used instead of a taxi. The distance is a straight line between points, but computationally addition, subtraction, multiplication, and division are all required. Table 11 shows the results for H1, H2, M1, M2, and M3, using 6 font groups with +3 spacing, a 3 x 3 harmonic space, and the top 1000 words.

H1, H2, and M3 were developed to test what appeared to be an asymptotic slope developing between the M1 and M2 cases. One premise was that sensitivity to error could be used to increase the percent correct rate. Instead, a maxima in performance occurred at M1. Though H1 and H2 out performs M2 and M3, it still does not perform better than M1. Though not presented, the following is also true for the 1 and 3 font group cases where the M1 distance calculation was the best measure of percent correct with respect to error values. The computationally quickest and simplest algorithm proves to be the best performer in this application and so it is used throughout the remaining research.

A note here is necessary concerning the Wedding Text font. It is usually excluded from the overall percent correct values because of its extreme variation in style and nonuse in font groups, but it is discussed in detail in subsection 4.2.7.

4.2.3 Spacing. Spacing is a very important issue when it comes to real world text. The amount of spacing between letters can vary from having overlapping characters to blank spaces between characters. If an algorithm could only distinguish words where the spacing is fixed, say at +3 pixels in width, then it is essentially useless in the real world. Both the 1 and 6 font group cases are explored for sensitivity to spacing. The harmonic search space is 3 x 3 and the top 1000 words used. Table 12 is the 1 font group case and Table 13 is the 6 font group case.

Given a font group composed of a single particular spacing (i.e. -7, +3, +9, etc). the algorithm is capable of distinguishing nearest neighbors regardless of whether the

Table 11. Comparison of Distance Calculations

	Distance Equations				
Font Style	H2	H1	M1	M2	M3
Avant Garde	95.5	95.4	96.3	96.0	95.0
Avant Garde bold	97.9	97.9	98.1	98.9	98.7
Brush	97.2	97.2	97.3	59.1	51.0
Zapf Chancery lght	99.4	99.1	99.6	99.3	98.3
Zapf Chancery lght ital	99.7	99.6	99.8	99.6	98.9
Zapf Chancery med	99.9	99.9	99.9	99.6	99.1
Zapf Chancery med ital	99.9	99.9	99.9	99.6	98.9
Eurostile	99.5	99.3	99.6	99.3	98.4
Eurostile bold	99.7	99.7	100.0	99.6	98.8
Garamound bold	99.8	99.8	99.9	89.6	86.7
Garamound bold ital	99.4	99.4	99.4	96.7	94.6
Garamound ital	99.1	99.1	99.6	98.7	97.2
Gill Kayo	99.6	99.6	99.8	83.3	75.5
Helena Script	96.9	96.9	97.5	33.0	19.8
Hobo	94.5	94.5	93.3	65.2	64.1
Janson	100.0	100.0	100.0	86.3	78.9
Megaron bold	100.0	100.0	100.0	99.9	99.7
Megaron bold ital	99.8	99.8	99.9	99.9	99.5
Megaron med	100.0	100.0	100.0	100.0	99.7
Megaron med ital	99.6	99.6	99.7	99.7	99.5
Schoolbook	100.0	100.0	100.0	92.1	85.9
Schoolbook bold	100.0	100.0	100.0	94.3	92.4
Schoolbook bold ital	98.5	98.5	99.3	99.4	97.6
Schoolbook ital	98.8	98.7	99.4	99.7	97.7
Wedding Text	74.3	74.4	76.5	70.2	66.7
overall % correct	98.0	97.9	98.2	90.4	87.7
% correct excluding fonts not used	98.9	98.9	99.1	91.2	88.6

Table 12. Spacing Comparisons of Font Group 1

	Spacing Between Letters			
Font Style	-5	-3	+3	+7
Avant Garde	70.7	72.1	78.0	82.6
Avant Garde bold	86.8	88.0	91.9	93.3
Brush	23.0	25.0	43.4	50.3
Zapf Chancery lght	92.0	90.6	93.4	94.4
Zapf Chancery lght ital	82.7	84.2	90.9	93.6
Zapf Chancery med	93.8	93.2	94.8	95.1
Zapf Chancery med ital	83.0	84.4	92.0	94.0
Eurostile	85.0	89.2	90.8	92.0
Eurostile bold	94.7	95.6	97.7	97.9
Garamound bold	93.1	92.3	92.4	92.9
Garamound bold ital	88.2	89.2	94.2	95.3
Garamound ital	91.1	92.0	94.9	95.9
Gill Kayo	79.5	81.8	87.2	89.7
Helena Script	21.8	23.0	32.0	37.3
Hobo	59.8	60.9	62.1	61.7
Janson	88.2	89.9	92.4	93.7
Megaron bold	95.6	95.5	97.5	97.3
Megaron bold ital	95.7	95.7	96.6	97.0
Megaron med	88.9	89.5	89.5	90.5
Megaron med ital	91.4	92.7	93.5	94.2
Schoolbook	95.9	96.3	98.4	98.5
Schoolbook bold	97.0	98.0	98.8	99.1
Schoolbook bold ital	97.1	96.6	97.7	97.7
Schoolbook ital	95.8	97.6	98.7	99.0
Wedding Text	63.9	66.1	71.5	74.1
overall % correct	82.2	83.2	86.8	84.4

Table 13. Spacing Comparisons of Font Group 6

	Spacing Between Letters			
Font Style	-7	-1	+3	+9
Avant Garde	85.8	93.0	96.3	97.6
Avant Garde bold	94.3	97.2	98.1	98.7
Brush	94.5	96.6	97.3	98.5
Zapf Chancery lght	98.0	98.9	99.6	99.7
Zapf Chancery lght ital	98.4	99.4	99.8	99.7
Zapf Chancery med	99.1	99.8	99.9	99.8
Zapf Chancery med ital	97.8	99.3	99.9	99.8
Eurostile	97.2	99.3	99.6	99.5
Eurostile bold	97.2	99.8	100.0	99.7
Garamound bold	100.0	99.9	99.9	99.8
Garamound bold ital	97.8	98.7	99.4	99.3
Garamound ital	97.8	99.7	99.6	99.6
Gill Kayo	99.9	99.6	99.8	99.7
Helena Script	95.0	95.8	97.5	98.4
Hobo	93.4	92.9	93.3	94.2
Janson	99.7	99.9	100.0	100.0
Megaron bold	99.2	100.0	100.0	100.0
Megaron bold ital	98.2	99.5	99.9	99.9
Megaron med	99.8	100.0	100.0	100.0
Megaron med ital	98.1	99.7	99.7	99.8
Schoolbook	99.8	99.9	100.0	100.0
Schoolbook bold	100.0	100.0	100.0	100.0
Schoolbook bold ital	97.4	98.8	99.3	99.5
Schoolbook ital	97.5	99.1	99.4	99.6
Wedding Text	61.5	69.2	76.5	78.2
overall % correct	95.9	97.4	98.2	98.4
% correct excluding Wedding Text font	97.3	98.6	99.1	99.3

characters are overlapped or are widely spaced. A logical question to ask is: what is the effect of using font styles from one spacing to identify font groups from another spacing. This will be discussed in subsection 4.2.8. The optimum number of harmonics to use in identifying nearest neighbors is the next variable to be addressed.

4.2.4 Number of Harmonics. Previous work by Bush (1) and O'Hair (13) was done with the 3rd harmonic vertically and horizontally giving a total of 49 coefficients: -3 to +3 (7) vertically and -3 to +3 (7) horizontally. It is undetermined, though, if 49 is the optimum number of coefficients. As the number of harmonics increases so does the sensitivity of the process to the wide variation in the values of the high frequency terms. It is the high frequency Fourier terms that characterize the ornate flare of a font style: curly ques and sharp edges of individual letters. By using the lower order harmonics, the images are essentially blurred to eliminate high frequency inputs. However, too much blurring causes errors like mistaking *after* for *often* or *came* for *come*. The goal is to find the optimum number of harmonics.

In English text, length is proportionally greater than height. This can be accounted for by increasing the number of harmonics used in the horizontal direction while holding the vertical direction constant. An example is a 3 x 5 search space. Using -3 to +3 (7) harmonics vertically and -5 to +5 (11) harmonics horizontally will yield 77 (7 x 11) unique components in the 2DFT. Any variety of combinations can be used. Table 14 presents the results of using the 6 font group case with the top 1000 words, where the energy has been renormalized based on the particular number of coefficients being used.

Three important results are present. The first is the importance of the horizontal axis versus the vertical axis. Successful identification is more sensitive to an increase in the horizontal. An example is 2 x 4 and 4 x 2. Both programs use 45 coefficients, yet their results are 99.4 percent correct versus 97.3 percent correct, respectively. The horizontal axis is more important for locating a correct neighbor. In fact, the 2 x 4 case with 45 coefficients performed better (0.4%) than the 3 x 3 case with 49 coefficients. A decrease of components in Fourier space but an increase in performance indicates higher information content in the horizontal axis.

Table 14. Harmonic Comparisons for Font Group 6 ‡

		Horizontal Harmonics				
		1	2	3	4	5
	1	68.3	92.2	95.8	98.4	98.6
Vertical	2	85.2	96.5	98.9	99.4	99.5
Harmonics	3	87.5	97.1	99.0	99.5	99.6
	4	88.5	97.3	99.1	99.5	99.6
	5	88.4	97.3	99.0	99.5	99.6

‡ *percent correct excluding Wedding Text font*

The second important result is the effect of increasing the number of harmonics in the algorithm. Increasing excessively the number of harmonics gives a diminishing return in performance. The 2 x 5 case results in 99.5 percent correct and it uses 5 x 11 (55) coefficients. The 5 x 5 case on the other hand, resulted in 99.6 percent correct. It used 11 x 11 (121) coefficients. Just over twice the number of coefficients develops only a 0.1% increase in the overall percent correct. While just over twice the number of coefficients from the 1 x 3 (21) case to the 2 x 4 (45) case produces a 7.2% increase in the overall percent correct.

The decreasing rate of return is not because the majority of energy is in the lower harmonics but because the lower harmonics best describes the general shape of the words. A special test proves this for the 2 x 3 case where its low frequency (-1 to +1) vertical and hoiizontal terms were set equal to zero. In effect, 26 coefficients (2 x 3 (35 coefficients) - 1 x 1 (9 coefficients)) are used; most (≥90 percent) of the total energy is zeroed out. The results are an impressive 98.2% correct (excluding Wedding Text) compared to 98.9% (excluding Wedding Text) using all Fourier terms. The 2 x 2 case uses 25 coefficients. Both the 2 x 2 and the 2 x 3 - 1 x 1 have essentially the same number of coefficients but

```
         V        HORIZONTAL --->
         E
         R  |
         T  |
         I  |          (*) - signifies coefficient used.
         C  V
         A
         L

      -4 -3 -2 -1  0  1  2  3  4           -4 -3 -2 -1  0  1  2  3  4
     ----------------------------          ----------------------------
 -4 |                            |     -4 |                            |
 -3 |                            |     -3 |                            |
 -2 |     *  *  *  *  *  *  *    |     -2 |        *  *  *  *  *       |
 -1 |     *  *           *  *    |     -1 |        *  *  *  *  *       |
  0 |     *  *           *  *    |      0 |        *  *  *  *  *       |
 +1 |     *  *           *  *    |     +1 |        *  *  *  *  *       |
 +2 |     *  *  *  *  *  *  *    |     +2 |        *  *  *  *  *       |
 +3 |                            |     +3 |                            |
 +4 |                            |     +4 |                            |
    |----------------------------|        |----------------------------|

           (2 x 3) - (1 x 1)                        (2 x 2)
```

Figure 11. Harmonic Groupings

an increase in overall percent correct of 1.7% occurs, in favor of the 2 x 3 - 1 x 1 case. Graphically, the two search spaces are presented in Figure 11.

An additional test is performed for the 2 x 2 case where the -1 to +1 terms are set to zero. The 2 x 2 terms minus the 1 x 1 terms gives 16 unique coefficients. The result is 90.5 percent correct. The 2 x 1 and 1 x 2 cases both have 15 coefficients in them and their results were 85.2 and 92.2 percent correct, respectively. Hence, the results for the 2 x 2 - 1 x 1, where t' majority of energy (-1 to +1 coefficients) is zeroed out, versus the 2 x 1 and the 1 x 2 cases shows that the algorithm is as sensitive to the high energy terms (1 x 1) as it is to the remaining lower energy terms around it. Therefore, the importance that any single coefficient plays in the algorithm making a successful nearest neighbor match is not based on the amount of energy within that particular coefficient but on the relative variance between the particular coefficient and a nearest neighbor coefficient. The first few harmonics are extremely valuable because these terms define the basic shape of a word, but a high percent correct ($\geq$ 95 percent) can be obtained with or without the high energy terms by using almost any combination of lower harmonics ($\leq$ 5), as long as the horizontal harmonics are emphasized ($\geq$) over the vertical harmonics *and* the total number of coefficients is roughly greater than 25.

The third important result is energy renormalization. When the number of coefficients are decreased, say from 121 to 49, and especially when the cosine DC term is eliminated (as in 2 x 2 - 1 x 1), the overall energy is no longer 1.0, assuming it is originally normalized for the 5 x 5 (121 coefficients) case. Hence, the surface of the 2^n hypersphere with unit radius r is now warped. Just like a ripe grape is round and smooth, so is the surface of a proper, energy normalized hypersphere. But when the energy of the components do not equal 1.0, the surface area plot becomes like a raisin. The results intuitively should produce a decrease in percent correct, but it does not.

Take for example the 1 x 3 case with and without energy renormalization, renormalization based on the number of coefficients used. The results are 95.8% and 97.3% correct, respectively. The percent correct for the 2 x 4 case with and without energy renormalization are identical (99.4%), even though the overall energy is of an image is 1.0 with renormalization and only 0.86 to 0.96 without renormalization. The majority of the energy is in the lower harmonics, but it is still unknown why the results improve.

Values in Table 14 word case differ slightly from Table 11 because of this renormalization. All previous tables to Table 14 have not been energy renormalized based on the number of harmonics used. In future tables it will be specified whether or not renormalization is being used.

4.2.5 Word Length. In Chapter 2, Table 7 shows for the adult reader that the word length is almost as important as the first letter and the meaning of a word. Because word length is so important to the human visual system, it is used here as a pre-processor or discriminator in the search space. Two cases are examined. The first case has the constraints listed in Table 15. The constraints imposed on the 6 font group case result

Table 15. Word Length Preprocessing

Assumed Length of Input Word	*Possible Length of nearest neighbor*
1	1 to 2
2	1 to 3
3	2 to 4
4	3 to 5
5	4 to 7
6	4 to 8
7	5 to 10
8 and up	6 and up

Table 16. Number of Possible Choices

Word Length	*Number of Possible Choices (max = 6000)*
1 letter	210
2 letters	774
3 letters	2028
4 letters	3048
5 letters	4198
6 letters	4674
7 letters	3846
8 and above letters	2742

in shortening the number of possible neighbors. They are derived by an assumption that length of words in a text stream can be approximated by height/length ratios and other simple calculations. The amount the length discriminator shortens the search space for individual word lengths is presented in Table 16.

The results of the algorithm for the top 1000 words using 6 font groups, a 3 x 3 harmonic space, with energy renormalization, is 99.0 percent correct. The search space has roughly half the original number of target (template) words as a result of length discrimination, but does not increase in percent correct. Improvement does not occur for two reasons. First, although the number of choices are decreased, the choices come from a location on the hypersphere that is already far away from the nearest neighbor and

Table 17. 1000 vs. 2000 Words

Harmonics Used (vertical x horizontal)	*1000 Words % correct (†)*	*2000 Words % correct (†)*	*5000 Words % correct (†)*
1 x 3	95.8	95.8	-
2 x 3	98.9	98.2	-
2 x 4	99.4	99.1	98.6
3 x 4	99.5	99.3	-
3 x ƹ	99.6	99.5	-

† = *excluding Wedding Text*

therefore does not adversely effect the results. And secondly, the total surface area in 2^n space is so large compared to the space used in this process that it can accommodate the large difference in choices.

The second case examines the effect of assuming an accurate length discriminator can be developed. The results show if the word length is known then the error rate for the top 1000 words using a 3 x 3 ha·monic space with the 6 font group case is only 0.7% (99.3% correct choices). This is not a drastic improvement (only 0.3%) considering the search space has been decreased an order of magnitude from 6000 to an average of less than 600 choices. This raises the question then: how many words can this Fourier space hold?

4.2.6 Number of Words. Since there are no obviously useful equations to tell when a 2^n hypersphere is filled, empirical data provides the only indication of the number of words possible in Fourier space. The second step in this process here is to increase the vocabulary from 1000 words is 2000 words. The list on the next 1000 most popular words is also listed in Appendix C. Given the same 25 font styles distributed into the same 6 font groups, Table 17 is a comparison between the 1000 and 2000 word cases.

The search space is doubled. 2000 words printed in 6 font groups make up 12000 target words for 50,000 input words (2000 words x 25 font styles). Little if any of the overall accuracy is lost. Consider the 2 x 3 case more closely. Table 18 compares the mean distance between nearest neighbors and change in standard deviation. The small change in mean distance is represented by the addition of 6000 target words in the output space.

Also included in Table 17 is the case for a 5000 word vocabulary. The 6 font groups make up 30,000 target words for the 125,000 input words. The largest percent of the increase in errors, from the 1000 to 5000 word case, occurs for the font styles that are used in font groups comprised of only two font styles. Never the less, little if any of the *overall* accuracy is lost. Therefore, the algorithm is shown capable of performing with a very large vocabulary.

4.2.7 Script Font. The algorithm's performance with the script fonts, Brush and Helena Script, proves to one of the most interesting findings. The performance is not as high as with most printed styles but then the script styles' variances are considerable, see Appendix A. They only have each other to make up the script font group. The algorithm's performance for the script fonts with a selected number of harmonic groups, using the top 1000 words, is presented in Table 19. These results are taken from the same programs which were used to develop Table 14.

The first thing which comes to sight is the mean and standard deviation values. They are almost identical for both font styles and upon further investigation of all other harmonic groups, this equality continues for both mean and standard deviation. Expanding this to other font styles that vary considerably from the majority of font styles (Hobo and Gill Kayo which makeup the *special* font group), it is evident that they too exhibit this behavior.

The results demonstrates that the algorithm handles script styles and printed styles the same in Fourier space. Neither one is more difficult to distinguish than the other. The percent correct is determined by the number of good font groups that exist to identify a particular font style. In the case of script fonts, only two font styles are used and so correct identification is limited to basically one font group. The algorithm performed similarily for the Hobo and Gill Kayo font styles and their percent correct values are also slightly less than the overall average.

The algorithm will work either on script or printed font styles regardless of their shapes. More ornate, stylish, or varied font styles must be well represented by the font

Table 18. 2 x 3 Harmonic Case for 2000 Words

	1000			2000		
Font Style	% cor	mean	std dev	% cor	mean	std dev
Avant Garde	95.9	0.72	0.20	94.3	0.69	0.19
Avant Garde bold	98.5	0.46	0.14	98.3	0.44	0.13
Brush	96.5	0.65	0.16	95.7	0.63	0.15
Zapf Chancery lght	99.5	0.65	0.22	98.9	0.61	0.21
Zapf Chancery lght ital	99.9	0.55	0.20	99.7	0.52	0.20
Zapf Chancery med	99.8	0.55	0.19	99.3	0.52	0.18
Zapf Chancery med ital	99.7	0.51	0.19	99.7	0.49	0.19
Eurostile	99.7	0.59	0.22	99.6	0.56	0.21
Eurostile bold	99.5	0.47	0.12	99.5	0.45	0.12
Garamound bold	99.8	0.45	0.11	99.8	0.44	0.11
Garamound bold ital	99.7	0.57	0.20	99.3	0.55	0.19
Garamound ital	99.6	0.57	0.18	99.3	0.54	0.18
Gill Kayo	98.7	0.43	0.16	97.2	0.43	0.16
Helena Script	96.8	0.65	0.16	96.2	0.63	0.15
Hobo	90.9	0.44	0.17	82.9	0.44	0.17
Janson	100.0	0.44	0.14	100.0	0.42	0.13
Megaron bold	100.0	0.34	0.11	100.0	0.33	0.10
Megaron bold ital	99.8	0.42	0.16	99.7	0.39	0.15
Megaron med	100.0	0.39	0.14	99.9	0.37	0.13
Megaron med ital	99.8	0.46	0.17	99.7	0.43	0.16
Schoolbook	100.0	0.41	0.11	100.0	0.39	0.10
Schoolbook bold	100.0	0.40	0.10	100.0	0.38	0.09
Schoolbook bold ital	98.9	0.59	0.17	98.7	0.57	0.16
Schoolbook ital	99.5	0.63	0.18	99.0	0.61	0.18
Wedding Text	74.9	0.83	0.31	74.8	0.78	0.29
overall % correct	97.9	0.51	-	97.2	0.50	-
excluding Wedding Text	98.9	-	-	98.2	-	-

Table 19. Script Fonts

Harmonics	*Overall*	*Brush*			*Helena Script*		
Used	% cor	% cor	mean	std dev	% cor	mean	std dev
1 x 2	92.2	80.4	0.28	0.08	82.7	0.29	0.08
1 x 4	98.4	97.5	0.51	0.15	96.0	0.51	0.15
2 x 2	96.5	90.9	0.48	0.11	90.2	0.49	0.11
2 x 4	99.4	98.9	0.82	0.21	97.9	0.82	0.21
3 x 2	97.1	93.0	0.67	0.14	92.1	0.67	0.15
3 x 4	99.5	99.1	1.10	0.26	98.2	1.10	0.26
4 x 4	99.5	99.2	1.30	0.29	98.9	1.30	0.29

Table 20. Wedding Text Font

Font Group	*Harmonics Used*	*Overall % Correct*	*Wedding Text*
1	1 x 1	39.0	32.1
1	2 x 2	75.5	63.5
1	3 x 3	86.3	71.5
1	5 x 5	91.2	78.7
6	1 x 2	92.9	58.2
6	2 x 4	99.4	77.7
6	3 x 3	99.0	75.6
6	4 x 4	99.5	79.1

group(s) in Fourier space. The more adequate the representation, (multiple font styles in font group) *usually* the higher the percent correct.

This is an appropriate time to discuss the Wedding Text. First, look at Appendix A and compare this font style with all others. It is not visually close to any other font style and, therefore, stands by itself. In this research, it is never included in any font group except the 1 font group case. A comparison of the algorithm's performance with the Wedding Text is presented in Table 20.

As extreme as the font style is and without its inclusion in any of the 6 font groups, the algorithm still performs in the high 70th percentile of correct choices. It is more important to explore how the algorithm handles something that it has not been trained with, which is completely different in style, than to force the Wedding Text into an ill-suited font group. This is an important question to ask for all the other font styles. How does the algorithm handle font styles that are not a member of any font group?

4.2.8 New font styles. What happens to the algorithm when a new font style is encountered? This question is of significance and is handled by testing each font style against font groups that have not been developed using that particular font style. The font groups are identical to the ones discussed in Chapter 3; except, when a particular font style is tested, it is excluded from the formation of any or all font groups. Hence, each font style is tested against font group(s) that have never seen that particular font style before. This is accomplished for the top 1000 words in a 3 x 3 harmonic space without energy renormalization. The results for the 1, 3, and 6 font group cases are consolidated in Table 21.

The biggest change is in the script font styles, Brush and Helena Script. These two are vastly different from printed text visually. Where as in the 1 font group case they make up 8.0% (2/25) of the font styles, they make up 100% of their font groups in the 3 and 6 font group cases. When eliminating either one from the font groups during testing, the remaining script font style makes up the entire font group. This results in losing the benefits from having a font group, and the algorithm is back to the original way of searching font styles against font styles, as in section 4.1.

This can also be noted in the 6 font group case for the two font styles (Hobo and Gill Kayo) that make up the *special* font group. They are the only two font styles that make up that particular font group and when either one is excluded from the group, the percent correct falls off rapidly. If overall percent correct is recalculated for the 3 and 6 font group cases and those font group which only have 2 font styles in a font group are excluded, then the percent correct is 96.0% and 98.0%, respectively.

It is possible to conclude, therefore, that if a font group is properly made with a variety of similar, yet varied font styles and then tested with a new font style, the percent correct will vary according to its similarity to the font groups. An ornate font style like Wedding Text will never produce 99 percent accuracies with the other font styles in appendix A. But for a more standard type of printed text (i.e. Megaron), the algorithm

Table 21. Introducing New Font Styles

	Number of Font Groups					
Font Style	1	1⋆	3	3⋆	6	6⋆
Avant Garde	78.0	71.2	94.0	89.6	96.3	93.7
Avant Garde bold	91.9	89.8	97.6	96.9	98.1	94.5
Brush	43.4	36.2	97.3	57.0	97.3	56.3
Zapf Chancery lght	93.4	90.9	99.6	97.6	99.6	97.6
Zapf Chancery lght ital	90.9	88.6	99.8	98.6	99.8	98.3
Zapf Chancery med	94.8	93.8	99.9	99.5	99.9	99.5
Zapf Chancery med ital	92.0	89.3	99.9	99.3	99.9	99.2
Eurostile	90.8	86.1	98.3	96.4	99.6	98.9
Eurostile bold	97.7	97.1	99.9	99.7	100.0	99.1
Garamound bold	92.4	92.0	93.4	92.1	99.9	99.2
Garamound bold ital	94.2	92.6	99.3	98.2	99.4	98.6
Garamound ital	94.9	93.3	99.6	98.5	99.6	98.4
Gill Kayo	87.2	82.5	89.1	89.1	99.8	93.9
Helena Script	32.0	24.7	97.5	48.2	97.5	49.5
Hobo	62.1	60.0	65.3	64.2	93.3	65.2
Janson	92.4	91.4	96.9	94.2	100.0	99.8
Megaron bold	97.5	97.1	100.0	99.7	100.0	100.0
Megaron bold ital	96.6	95.2	99.4	98.9	99.9	99.2
Megaron med	89.5	86.3	98.7	98.0	100.0	99.9
Megaron med ital	93.5	90.6	99.4	98.8	99.7	99.3
Schoolbook	98.4	97.3	99.4	99.1	100.0	99.9
Schoolbook bold	98.8	97.3	99.5	99.2	100.0	99.8
Schoolbook bold ital	97.7	97.9	94.9	93.8	99.3	94.8
Schoolbook ital	98.7	96.7	96.9	96.4	99.4	95.0
Wedding Text	71.5	68.8	71.5	71.5	76.5	76.5
overall % correct	86.8	84.3	95.5	91.0	98.2	92.9

(⋆) - font style not part of any font group and therefore considered a new font style.

operates at nearly peak performance even though the particular font is not part of any font group.

The human brain actually seems to behave the same way. Given a new ornate font style, reading speed is severely reduced. With practice, reading speed will gradually increase to its usual performance with previously well known font styles. If the style is not an extremely different one, then reading speed is only slightly reduced when first viewing it. The lesson then is to build a machine using a representative cross section that is able to interpret the majority of font styles that might be encountered.

4.2.9 Font from new spacing. The variation between spacing is another important issue. In subsection 4.2.3, the research proved spacing did not severely affect recognition. But what happens when training of the font groups comes from one spacing and the examined text is from a different spacing? To answer this question, four spacings are considered. They are -5, +1, +3, and +7. They represent a -31% to +44% change in average word length. The font groups are made with one particular spacing and then the input words are taken from a second different spacing. The top 1000 words are used with a 3 x 3 harmonic space and the 6 font group case. The combinations tested are presented in Table 22. Energy renormalization is not performed and not all -5 spacings are tested. In addition to this, the average change in word length between input word and target word is listed in Table 23. It is based on the relationship between letter spacing (-5, +1, +3, and +7 pixels) and the average letter length, which is 16 pixels.

A special note concerning the -5 spacing is necessary. Recall from Figure 10 what a -5 spacing looks like. Additional examples are shown in Figure 12. Large distortion occurs where *cl* now becomes *d*, *to* becomes *b*, and so on. The test was made to determine if the algorithm can work on really distorted images of a word. The results may be a little misleading when -5 spacing is compared to +1 spacing, and +7 spacing; actually the human visual system can do no better in deciding it *d* is either a *d* or a *cl* pushed together. Therefore, it is not a break down in the algorithm but a break down in symbology. The meaning of the symbol or character is lost when overlap is too great.

Examine the remaining cases of +1, +3, and +7. As the percent of increase in

Table 22. Percent Correct from New Spacing

		Input Word Spacing			
		-5	+1	+3	+7
	-5	97.8	78.2	†	†
Font Group	+1	80.2	99.0	98.9	97.3
Spacing	+3	†	98.6	99.1	98.7
	+7	41.5	93.9	98.0	99.2

† = *not tested.*

Table 23. Percent Change in Length

		Input Word Spacing			
		-5	+1	+3	+7
Font Group	-5	0	38	†	†
Spacing	+1	38	0	13	38
	+3	†	13	0	25
	+7	75	38	25	0

† = *not tested.*

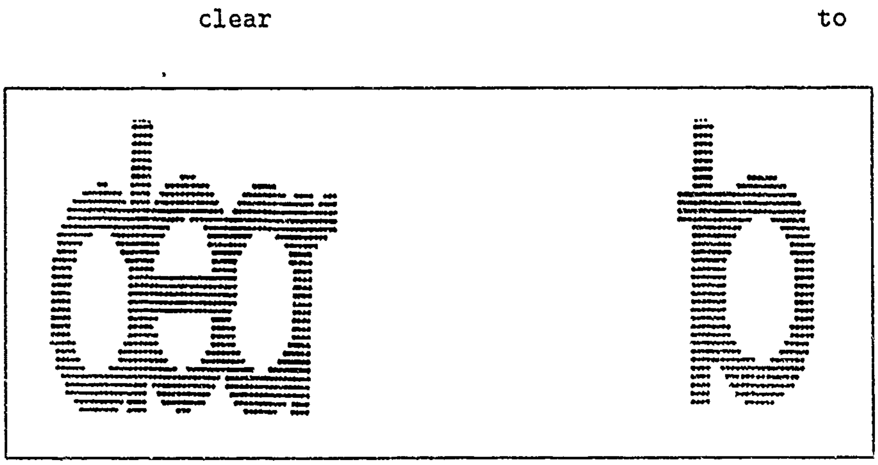


Figure 12. Additional Images In Avant Garde Font Style With a -5 Pixel Spacing

spacing within a word grows, the percent correct between different spacings decreases. This indicates the possible need for multiple font groups with varied spacing. Depending on the reduction of percent correct allowable, the necessary number of font groups based on spacing can be calculated. Note that after about a +7 spacing, the letters within a word can freely be segmented and the algorithm applied to the individual letters themselves. Therefore, many different font groups based on spacing are not required. Only about 2 or 3 spacings would ever be necessary in actual text.

4.2.10 Noise. Up until now, all images of words used in this research have been considered noiseless. In a real world case, this never happens and this research now investigates three cases where noise is added to the data previously generated. The first is covered in subsection 4.2.4 where the energy normalization is not uniform. The effect of improperly normalizing the energy is equivalent to varying the intensity in the input image. With a 10% variance in energy in Fourier space, the results produced a moderate (1 x 3 harmonic case) to slight (2 x 4 harmonic case) increase in percent correct. This addition of noise actually benefits recognition. The answer to this is unpredictable and at present unexplainable.

The second case was discovered by accident. It involved incorrectly building one of the font groups for the top 2000 words, 6 font group case. The first 1000 words of the

Table 24. Inadvertent Error in the 2000 Word Case

Font Group 'regular a' word		*font style 1* word		*font style 2* word		*font style 3* word		*font style 4* word		*font style 5* word
1 the	=	the	+	the	+	the	+	the	+	covered (1001)
2 of	=	of	+	of	+	of	+	of	+	current (1002)
3 and	=	and	+	and	+	and	+	and	+	despite (1003)
4 to	=	to	+	to	+	to	+	to	+	eight (1004)
5 a	=	a	+	a	+	a	+	a	+	i'd (1005)
.									.	
.									.	
.									.	
1000 won't	=	won't	+	won't	+	won't	+	won't	+	joe (2000)

where:
font style 1 = Avant Garde
font style 2 = Avant Garde bold
font style 3 = Schoolbook bold italicized
font style 4 = Schoolbook italicized
font style 5 = Wedding Text

'regular a' font group (Avant Garde, Avant Garde bold, Schoolbook bold italicized, and Schoolbook italicized) were accidentally added with the second 1000 words of the Wedding Text font style. Hence, the following in Table 24 is a partial list of what happened.

The most popular word, *the*, should have been a composite of 4 different *the*'s. Actually it is made up of 5 words, 4 *the*'s and the word *covered.* The second most popular word *of* is a composite of 4 different *of*s and the word *current.* This error occurred for the first 1000 words of the 'regular a' font group. In addition to this 'noise', the images were energy normalized for only 4 words and not the 5 which occurred. So, not only were the images greatly corrupted, but their energy normalization is incorrect. The results of this top 2000 word test using the 6 font group [illegible] with a 3 x 3 harmonic search space are listed in Table 25.

The most important result is only a moderate decrease in performance occurred for the font styles which make up the 'regular a' font group. The noise did not affect other font

Table 25. Percent Correct for Added Noise to 2000 Words

	Correct 2000			*Corrupted* 2000		
Font Style	% cor	mean	std dev	% cor	mean	std dev
Avant Garde	95.3	0.91	0.25	92.0	0.90	0.26
Avant Garde bold	98.3	0.58	0.18	97.3	0.60	0.20
Brush	98.5	0.80	0.20	98.5	0.76	0.19
Zapf Chancery lght	99.5	0.82	0.28	99.4	0.77	0.25
Zapf Chancery lght ital	100.0	0.70	0.26	99.9	0.66	0.24
Zapf Chancery med	99.7	0.70	0.24	99.7	0.67	0.22
Zapf Chancery med ital	99.7	0.66	0.26	99.7	0.62	0.24
Eurostile	99.5	0.74	0.28	99.7	0.71	0.26
Eurostile bold	99.3	0.59	0.17	99.5	0.58	0.16
Garamound bold	100.0	0.56	0.14	100.0	0.53	0.13
Garamound bold ital	99.3	0.73	0.25	99.4	0.70	0.23
Garamound ital	99.5	0.73	0.24	99.5	0.69	0.22
Gill Kayo	99.3	0.54	0.20	99.4	0.53	0.19
Helena Script	98.3	0.80	0.20	98.2	0.76	0.19
Hobo	94.7	0.55	0.20	94.8	0.54	0.19
Janson	100.0	0.55	0.18	100.0	0.53	0.16
Megaron bold	99.9	0.43	0.13	99.9	0.42	0.13
Megaron bold ital	99.6	0.54	0.21	99.3	0.54	0.21
Megaron med	100.0	0.50	0.18	100.0	0.48	0.17
Megaron med ital	99.7	0.59	0.23	99.7	0.57	0.22
Schoolbook	100.0	0.51	0.14	100.0	0.48	0.13
Schoolbook bold	100.0	0.48	0.12	100.0	0.47	0.11
Schoolbook bold ital	99.5	0.75	0.22	96.2	0.79	0.26
Schoolbook ital	99.5	0.81	0.24	96.5	0.84	0.26
Wedding Text	77.5	1.05	0.38	78.2	0.99	0.36
percent correct (†)	99.1	0.66	-	98.7	0.65	-

(†) - percent correct excludes Wedding Text

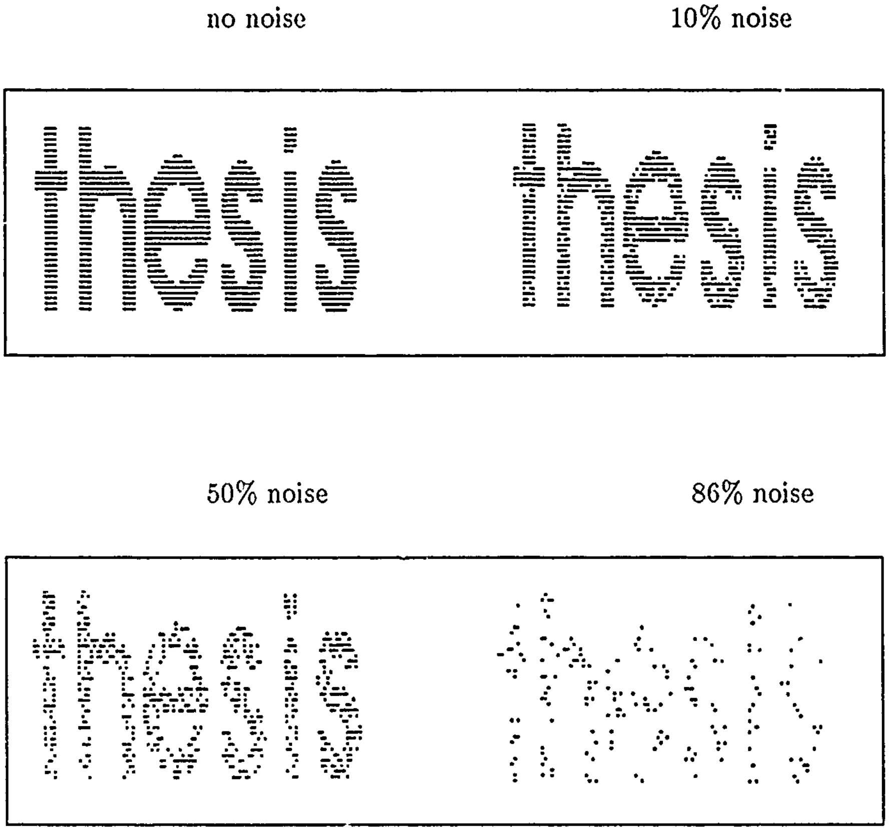


Figure 13. Random Noise on the Word 'thesis' in Avant Garde Font Style

groups but is isolated to the group in which it originated. The second important result is the amount by which the noise decreased the percent correct for the 'regular a' font group. Calculating the 'regular a' font group correctly, the percent correct for these 4 font styles is 98.2%. With the noise it is 95.5%. Thus when 50% of the 'regular a' font group's words are corrupted, an average decrease of only 2.7% occurs.

This leads to a more structured way of generating noise in the input image. All coefficient values for the top 1000 words with +3 spacing are recomputed with a random noise value. The input images of the words are degradated by a selected noise percentage. This amount ranges from 10% to 86%. The image of each word is built with a percentage of the pixels randomly whited out. Figure 13 is an example of the 10%, 50%, and 86% cases. The font group coefficients values are derived from noiseless images and the test input words are made from noisy images.

Table 26. Effects of Noise on the 1 x 3 Harmonic Search Space

Font Style	Noiseless	10%	20%	50%	86%
Avant Garde	84.8	85.8	83.9	76.2	34.0
Avant Garde bold	97.1	97.6	97.0	91.9	52.4
Brush	93.7	93.8	93.0	84.1	46.2
Zapf Chancery lght	98.1	97.8	96.8	88.5	40.9
Zapf Chancery lght ital	98.8	98.2	97.7	93.2	50.5
Zapf Chancery med	98.0	97.8	96.9	90.5	43.3
Zapf Chancery med ital	99.1	98.5	98.4	93.5	52.9
Eurostile	99.1	97.7	97.9	89.2	37.2
Eurostile bold	97.3	96.5	95.2	92.1	49.1
Garamound bold	99.1	98.9	98.8	94.3	52.3
Garamound bold ital	97.4	96.2	95.3	91.2	53.1
Garamound ital	98.2	97.5	97.3	91.5	50.6
Gill Kayo	95.8	95.6	93.9	85.7	37.7
Helena Script	93.0	91.3	88.4	79.9	47.2
Hobo	88.9	87.0	86.1	81.5	42.1
Janson	99.7	99.4	99.1	93.3	46.3
Megaron bold	99.7	99.6	99.5	96.1	53.8
Megaron bold ital	98.1	98.2	97.9	92.3	50.5
Megaron med	99.7	99.7	99.1	96.9	48.5
Megaron med ital	99.5	99.7	98.9	96.2	41.9
Schoolbook	99.7	98.9	98.4	95.1	55.0
Schoolbook bold	99.6	99.6	99.7	96.6	54.5
Schoolbook bold ital	97.4	96.4	95.7	91.6	53.7
Schoolbook ital	97.2	96.8	95.0	89.1	45.7
Wedding Text	68.9	66.8	63.9	53.3	24.6
overall % correct	95.8	95.4	94.6	89.0	46.6
excluding Wedding Text	96.9	96.6	95.8	90.4	47.5

Once the 2DFT of the 25,000 images (1000 words x 25 font style) are computed, for each of the separate noise values (10, 20, 50, and 86%), the nearest neighbor calculations are handled just as before. The results for the top 1000 words using the 6 font group case, with energy renormalization and both 1 x 3 and 2 x 4 harmonic spaces are presented in Tables 26 and 27, respectively.

It is evident from Tables 26 and 27 that the algorithm is *not* sensitive to noise. There is a slow degradation of the results as the input images become noisier, but for small to moderate amounts of noise (10 to 20%), the algorithm is essentially unaffected by noise.

Table 27. Effects of Noise on the 2 x 4 Harmonic Search Space

Font Style	Noiseless	10%	20%	50%	86%
Avant Garde	95.7	95.5	95.6	93.9	69.9
Avant Garde bold	99.0	99.0	99.1	98.2	80.5
Brush	98.9	98.2	97.2	95.1	70.8
Zapf Chancery lght	99.3	99.3	99.2	98.0	70.5
Zapf Chancery lght ital	100.0	100.0	100.0	99.5	78.7
Zapf Chancery med	99.9	99.9	99.7	99.1	76.1
Zapf Chancery med ital	99.7	99.5	99.6	98.6	76.6
Eurostile	99.4	99.5	99.2	98.2	73.0
Eurostile bold	99.5	99.6	99.3	98.7	79.3
Garamound bold	100.0	99.9	100.0	99.8	86.1
Garamound bold ital	99.7	99.7	99.6	98.7	79.4
Garamound ital	99.7	99.9	99.7	99.0	79.2
Gill Kayo	99.8	99.5	99.5	98.8	76.6
Helena Script	97.9	97.1	96.7	94.1	68.2
Hobo	98.5	98.0	98.1	94.8	76.6
Janson	100.0	99.9	100.0	99.6	84.6
Megaron bold	100.0	100.0	99.8	99.7	86.0
Megaron bold ital	99.9	99.7	99.8	99.3	82.3
Megaron med	100.0	99.9	99.9	99.8	82.1
Megaron med ital	99.9	99.8	99.8	99.1	77.5
Schoolbook	100.0	100.0	100.0	99.6	87.2
Schoolbook bold	100.0	100.0	100.0	99.8	88.0
Schoolbook bold ital	99.9	99.6	99.7	98.5	82.6
Schoolbook ital	99.9	99.9	99.6	98.7	79.7
Wedding Text	77.7	77.4	76.4	71.1	43.3
overall % correct	98.5	98.4	98.3	97.2	77.4
excluding Wedding Text	99.4	99.3	99.2	98.3	78.8

This is especially true for the 2 x 4 harmonic case. For use in a reading machine this is of great importance since input images are rarely 100% noiseless.

4.2.11 Upper case letters. Common text is rarely capitalized for any extended period. But for the cases where it does occur, it is important to know how well the algorithm performs is investigated. Consider four test cases where:

1. no font groups used: original approach of section 4.1
2. 1 font group case is used
3. 6 font group case used
4. 6 font group case used but font styles rearranged into new font groups.

The change in font groups between the previous 6 font group case and the new proposed one for capital letters is shown in Table 28.

The results for these 4 test cases using a 3 x 3 harmonic space with the top 1000 words and energy renormalization are shown in Table 29.

It is obvious that the algorithm for the 1 font group case, like in the lower case, is superior to the original search method in section 4.1. It is not superior though to the 1 font group case of the using the lower case alphabet because the upper case letters are more ornate. Examine Appendix A again and compare the wide range of font styles. These uppercase font styles are vastly different and varied from the previous work in my Master's thesis (13). Not only is the search space greatly increased, but the florid design of the font styles increases the difficulty of recognition.

The old and new divisions in the 6 font groups reveal the importance of good font group construction. The old 6 font group case is divided according to lower case variance of the letters *a* and *g*. This does not necessarily apply to the upper case variances. The new font groups are grouped based on *overall* letter variances. I did this subjectively. This, too, may not be the optimum division of font styles into font groups, but notice the increase in percent correct. The new 6 font group case is also tested using different harmonics spaces. The results for the top 1000 words are shown in Table 30

Table 28. New and Old Font Groups for Capitals

Previous Font Group	*Font Styles*	*New Font Group*	*Font Styles*
italics	Zapf Chancery lt	fg1	Zapf Chancery med
	Zapf Chancery lt ital		Garamound bold ital
	Zapf Chancery med		Garamound ital
	Zapf Chancery med ital		Schoolbook bold ital
	Garamound bold ital		Schoolbook ital
	Garamound ital		
		fg2	Avant Garde bold
regular a	Avant Garde		Eurostile bold
	Avant Garde bold		Gill Kayo
	Schoolbook bold ital		Hobo
	Schoolbook ital		
		fg3	Avant Garde
regular *a* g	Eurostile		Eurostile
	Eurostile bold		Megaron bold
	Megaron bold		Megaron bold ital
	Megaron bold ital		Megaron med
	Megaron med		Megaron med ital
	Megaron med ital		
		fg4	Zapf Chancery lt
regular *a g*	Garamound bold		Garamound bold
	Janson		Janson
	Schoolbook		Schoolbook
	Schoolbook bold		Schoolbook bold
script	Brush	fg5	Brush
	Helena Script		Zapf Chancery med ital
			Zapf Chancery lt ital
special	Gill Kayo		
	Hobo	fg6	Helena Script
			Wedding Text
not used	Wedding Text		none

Table 29. Percent Correct for Capital Letters

Font Style	*Original*	*1 Font Group*	*6 Font Group(old)*	*6 Font Group(new)*
Avant Garde	94.0	98.2	99.6	99.9
Avant Garde bold	76.5	96.0	98.4	99.9
Brush	8.2	42.3	99.2	91.6
Zapf Chancery lght	95.9	98.0	98.1	99.8
Zapf Chancery lght ital	96.6	44.0	86.7	100.0
Zapf Chancery med	92.8	97.9	98.7	99.6
Zapf Chancery med ital	95.9	33.6	78.4	99.9
Eurostile	81.4	86.0	99.4	99.4
Eurostile bold	92.3	97.8	99.2	100.0
Garamound bold	93.1	99.9	100.0	100.0
Garamound bold ital	99.2	99.1	99.0	100.0
Garamound ital	99.8	99.0	98.7	100.0
Gill Kayo	31.2	48.7	99.8	97.2
Helena Script	0.6	6.6	58.5	88.6
Hobo	76.5	96.5	99.8	98.5
Janson	96.7	99.7	100.0	100.0
Megaron bold	97.1	99.9	100.0	99.9
Megaron bold ital	94.3	100.0	99.9	99.6
Megaron med	98.2	98.8	100.0	100.0
Megaron med ital	96.8	98.8	99.9	100.0
Schoolbook	97.1	99.1	100.0	99.8
Schoolbook bold	96.3	99.0	99.9	99.5
Schoolbook bold ital	99.2	97.3	99.8	99.6
Schoolbook ital	99.0	96.3	99.9	99.5
Wedding Text	0.2	4.1	1.4	66.8
overall % correct	80.4	81.5	92.6	97.6
excluding Wedding Text	n/a	n/a	96.4	98.8

Table 30. Different Harmonic Groups for Capitals

	Harmonics			
Font Style	1 x 1	1 x 4	3 x 3	2 x 5
Avant Garde	79.1	98.6	99.9	98.8
Avant Garde bold	72.6	99.2	99.9	99.9
Brush	23.5	68.6	91.6	94.1
Zapf Chancery lght	28.3	96.4	99.8	100.0
Zapf Chancery lght ital	72.3	99.8	100.0	100.0
Zapf Chancery med	59.2	97.4	99.6	99.4
Zapf Chancery med ital	71.4	99.7	99.9	100.0
Eurostile	41.4	98.3	99.4	99.7
Eurostile bold	69.5	99.5	100.0	100.0
Garamound bold	80.9	99.7	100.0	100.0
Garamound bold ital	95.1	99.8	100.0	100.0
Garamound ital	90.1	99.4	100.0	100.0
Gill Kayo	37.4	88.0	97.2	99.4
Helena Script	9.5	89.1	88.6	98.6
Hobo	73.8	99.1	98.5	99.6
Janson	91.5	100.0	100.0	100.0
Megaron bold	78.3	100.0	99.9	100.0
Megaron bold ital	60.6	99.2	99.6	99.8
Megaron med	97.2	100.0	100.0	100.0
Megaron med ital	93.3	99.9	100.0	100.0
Schoolbook	89.5	99.8	99.8	100.0
Schoolbook bold	51.5	98.6	99.5	99.9
Schoolbook bold ital	67.4	99.1	99.6	100.0
Schoolbook ital	82.8	99.3	99.5	100.0
Wedding Text	2.6	31.5	66.8	77.8
overall % correct	64.7	94.4	97.5	98.6
excluding Wedding Text	67.3	97.0	98.8	99.5

Table 31. Font Groups for Numbers

Font Style (†)	*1 Font group* font group names	*3 Font group* font group names
Avant Garde	fg1	reg1
Brush	fg1	reg2
Zapf Chancery med ital	fg1	reg2
Eurostile	fg1	reg1
Garamound bold	fg1	script
Garamound bold ital	fg1	script
Megaron bold	fg1	reg1
Schoolbook bold	fg1	reg1

† - See Appendix A for the shape of the font style chosen

The overall result is the algorithm performs as well for uppercase letters as with lower case letters. But a significant improvement occurs when font styles are properly arranged into font groups. These groupings are not necessarily the same for lower and [illegible]r case alphabets.

4.2.12 Numbers. So far the algorithm has been applied to lower and upper case letters, printed and script text, plain and ornate letters, and all in a variety of type settings. Performance has ranged from acceptable to outstanding, but consider a new set of symbols: numbers. This work is performed on a subset of the 25 font groups. Only eight font styles are chosen because the variance in numerical shapes for the 25 different font styles is limited. Also using the subset of eight font styles increases the processing speed. The eight font styles chosen are picked for their variation in style from one another. At least two fairly similar font styles are used for each font group and then varying font styles are picked to distinguish font groups. The font styles picked for the font groups are shown in Table 31.

The numerical sequence 000 to 999 is chosen as a test case. The image of each three digit number is built using each of the eight font styles. The 2DFT of the images are computed and stored. The approach is identical to the image of words except that numbers are used as symbols instead of letters. The results using the 1000 3 digit numbers

Table 32. Percent Correct for Numbers 000 to 999

	1 Font group			*3 Font group*		
Font Style	-3	+1	+5	-3	+1	+5
Avant Garde	97.4	97.3	95.6	97.7	99.2	99.4
Brush	62.6	63.7	60.5	99.4	97.9	95.9
Zapf Chancery med ital	55.6	60.1	59.7	93.7	86.1	82.4
Eurostile	50.4	57.9	48.5	85.4	91.2	89.6
Garamound bold	95.2	92.7	91.4	100.0	100.0	100.0
Garamound bold ital	89.9	87.1	83.9	100.0	100.0	100.0
Megaron bold	82.6	92.8	91.3	90.3	95.0	94.4
Schoolbook bold	83.9	84.8	79.0	84.3	80.0	79.8
overall % correct	77.2	79.6	76.2	93.9	93.7	92.7

in a 3 x 3 harmonic space are shown in Table 32.

The results are not as promising as the case with letters. This is probably due to the fact that the number of font styles which make up the font groups are small. Also, the mean distances between numbers is proportionally smaller than the mean distances between letters. This is mainly because the top 1000 words are not all the same length as are the 1000 numerical symbols. If all the 1000 three letter word combinations using just ten separate letters were compiled, I doubt that the results would be any different.

4.3 Special Distance Calculations

4.3.1 Three Part Look. To obtain an algorithm that is 100% correct for the 1000 word case, the three special distance calculations are developed. These three algorithms are described in section 3.5. The first case is the image of a word broken into three parts. The 2DFT for each word is computed, both for the complete image and for the three parts (first, middle, and last third) of the image. It was thought if all the correct answers lie within some number (first, second, third ...choice) of neighbors from the input word, then it might be possible to choose the correct answer from this list and rule out false recognitions. Table 33 is a list of percent correct with respect to the combined top 1, 3, and 5 choices of nearest neighbors. Instead of just recording the single nearest neighbor, the second, third, etc. choices are also recorded. This table uses the top 1000 words with

3 x 3 harmonic search space for the 3 font group case.

Assuming the correct answers can now be chosen from a list of just five choices, instead of 3000 (3 font groups x 1000 words), the overall percent correct will increase from 95.5 to 97.7 percent correct. Ruling out the effects of the varied font styles *Hobo* and *Wedding Text*, this percent correct jumps from 96.8 to 99.8. The three part search is an attempt to achieve such an increase in recognition.

The results are somewhat disappointing. The best choice is chosen from the five nearest neighbors based on the smallest combined total distance from the three parts (first, middle, and last) of the word. Each word in the list of five neighbors is treated equally, and selection from this subgroup is solely based on the 2DFT of the three parts. Table 34 compares the previous results of the 3 font group case with the 1000 top words and a 3 x 3 search space and the new results after searching the five nearest neighbors based on the three parts of the image.

Examining the specific errors in each column reveals the three part scheme is making some adjustments but introduces a new group of errors. Selecting three of the font styles for a closer examination (Avant Garde, Janson, and Megaron bold) shows that for Avant Garde, 30% of the errors in the first column are corrected, but 95% more errors overall were added. This information came from an additional list of all errors and their nearest neighbors that is recorded at the same time the percent correct figures is computed. For Janson, 100% of the errors are corrected through this scheme, but 174% more errors are created. For Megaron bold, no errors occurred previously, but only 98.8% correct are obtained through the 3 part scheme. The final result is that this special case that uses the Fourier coefficients of the first, middle, and last thirds of a word as a post-processor is not effective in improving the performance of the algorithm. It does solve the majority of the previous errors, but in the process creates more errors overall.

4.3.2 Learn Font Groups. Section 3.5 touches on the fundamentals involved in making the special transforms for each font group, but the actual amount of training used is three distinct passes. The first two passes by the program through the font groups uses the first 200 of the top 1000 words. For each of the nearest neighbors, a record is kept concern-

Table 33. Percent Correct for Combined Nearest Neighbors

Font Style	*Nearest Neighbor*	*Nearest 3 Neighbors Combined*	*Nearest 5 Neighbors Combined*
Avant Garde	94.0	99.5	99.8
Avant Garde bold	97.6	99.7	99.9
Brush	97.3	99.9	100.0
Zapf Chancery lght	99.6	100.0	100.0
Zapf Chancery lght ital	99.8	100.0	100.0
Zapf Chancery med	99.9	100.0	100.0
Zapf Chancery med ital	99.9	100.0	100.0
Eurostile	98.3	100.0	100.0
Eurostile bold	99.9	100.0	100.0
Garamound bold	93.4	97.4	98.0
Garamound bold ital	99.3	100.0	100.0
Garamound ital	99.6	100.0	100.0
Gill Kayo	89.1	97.1	98.6
Helena Script	97.5	100.0	100.0
Hobo	65.3	66.4	67.3
Janson	96.9	99.7	100.0
Megaron bold	100.0	100.0	100.0
Megaron bold ital	99.4	100.0	100.0
Megaron med	98.7	100.0	100.0
Megaron med ital	99.4	100.0	100.0
Schoolbook	99.4	100.0	100.0
Schoolbook bold	99.5	100.0	100.0
Schoolbook bold ital	94.9	99.0	99.8
Schoolbook ital	96.9	99.1	99.7
Wedding Text	71.5	77.4	80.2
overall % correct	95.5	97.4	97.7
% correct excluding Hobo and Wedding Text	96.8	99.6	99.8

Table 34. Percent Correct for 3 Part Scheme

Font Style	*Previous Results*	*3 Part Scheme*
Avant Garde	94.0	83.3
Avant Garde bold	97.6	95.2
Brush	97.3	97.0
Zapf Chancery lght	99.6	97.9
Zapf Chancery lght ital	99.8	98.8
Zapf Chancery med	99.9	98.3
Zapf Chancery med ital	99.9	98.9
Eurostile	98.3	90.3
Eurostile bold	99.9	96.2
Garamound bold	93.4	94.6
Garamound bold ital	99.3	98.5
Garamound ital	99.6	98.5
Gill Kayo	89.1	85.0
Helena Script	97.5	98.5
Hobo	65.3	64.5
Janson	96.9	94.6
Megaron bold	100.0	98.9
Megaron bold ital	99.4	98.0
Megaıon med	98.7	96.6
Megaron med ital	99.4	96.0
Schoolbook	99.4	97.4
Schoolbook bold	99.5	99.0
Schoolbook bold ital	94.9	90.2
Schoolbook ital	96.9	91.1
Wedding Text	71.5	67.6
overall % correct	95.5	93.0
% correct excluding Hobo and Wedding Text	96.8	95.3

ing which font group is selected and the numerical difference between font style coefficient values and font group coefficient values. The normalized cumulative difference is then subtracted from the font group coefficient values. This cumulative difference approaches 0.0 as the number of passes increases. It was determined that in just two training passes, approximately 98% of the total cumulative difference values could be obtained. Therefore, on the third pass, the entire 1000 words are used for nearest neighbor calculations.

Table 35 is developed using the top 1000 words with a 3 x 3 harmonic search space. The transform coefficient values for any font group which is used less than 10 times during the 200 training passes is energy normalized to 10% of its value. This is done because the transform becomes too specialized if the number of samples is too small ($\leq$10). Normalizing the transform's energy prevents over-specialization of the font groups.

Table 36 is a composition of varying harmonic values used with this new technique. It is combined with the results of Table 14 section 4.2.4 and also excludes using the Wedding Text font style. Improvements are greatest in the lower harmonic terms. When input information (number of coefficients) is low, the transform makes a greater improvement over the conventional algorithm. When information increases, the benefits of the transform values on each font group is reduced.

Two important ideas evolve here. First, using a subset of the top 1000 words gives transform values that will improve all of the distance calculations between font style and font groups. Put another way, analyzing how a font style differs between a font group for a few particular words will improve its ability to recognize all other words. The program learns to recognize the overall characteristics of a particular font style and not just individual letter characteristics.

The second idea is that smaller harmonic groups can be used to obtain performance levels of larger harmonic groups. The reduction of input data (number of coefficients) can be augmented through transform use to obtain results equivalent to an increase in input data. Essentially, it is doing more with less through the use of the transforms by preprocessing the information.

Table 35. Learn Font Groups using Special Transforms

Font Style	*Previous Results*	*Learn Font Groups*
Avant Garde	96.3	96.5
Avant Garde bold	98.1	98.3
Brush	97.3	98.1
Zapf Chancery lght	99.6	99.7
Zapf Chancery lght ital	99.8	99.7
Zapf Chancery med	99.9	99.8
Zapf Chancery med ital	99.9	99.9
Eurostile	99.6	99.6
Eurostile bold	100.0	99.9
Garamound bold	99.9	99.9
Garamound bold ital	99.4	99.4
Garamound ital	99.6	99.5
Gill Kayo	99.8	99.6
Helena Script	97.5	97.8
Hobo	93.3	96.7
Janson	100.0	100.0
Megaron bold	100.0	100.0
Megaron bold ital	99.9	99.8
Megaron med	100.0	100.0
Megaron med ital	99.7	99.7
Schoolbook	100.0	100.0
Schoolbook bold	100.0	100.0
Schoolbook bold ital	99.3	99.8
Schoolbook ital	99.4	99.7
Wedding Text	76.5	75.8
overall % correct	98.1	98.4
excluding Wedding Text	99.0	99.3

Table 36. Harmonic Variations for Learned Font Groups using Special Transforms

		Horizontal Harmonics				
		1	2	3	4	5
	1	68.3/73.2	92.2/93.7	95.8/97.8	98.4/⋆	98.6/⋆
	2	85.2/⋆	96.5/97.2	98.9/⋆	99.4/⋆	99.5/99.6
Vertical	3	87.5/⋆	97.1/⋆	99.0/99.3	99.5/⋆	99.6/⋆
Harmonics	4	88.5/⋆	97.3/⋆	99.1/⋆	99.5/⋆	99.6/99.6
	5	88.4/⋆	97.3/⋆	99.0/⋆	99.5/⋆	99.6/⋆

(Table 14 results/algorithm using transform)
(⋆) - not calculated.

4.3.3 Look Three Ways. The final attempt to achieve 100% for the top 1000 words using the 6 font group case is to capitalize on the fact that different harmonic groups (i.e. 1 x 3, 2 x 5, ect.) produce different errors. Even though the overall percent correct for the 2 x 5 harmonic case is equivalent to the 4 x 4 harmonic case, the individual errors are not all the same. Three separate harmonic groups are chosen to be as different as possible. This is done by dividing the 121 total coefficients possible (the 5 x 5 case contains 121 coefficients) into three separate groups. Each group is required to achieve a minimum overall percent correct of ≥95%. To accomplish this, some over lapping between the three groups is necessary.

Ten 3 group cases were tested. Two of the ten are selected for discussion. They are not necessarily the best performers, but they give an overview as to what happened. Figure 14 shows the first case of three harmonic groups used to select a best neighbor for the top 1000 words using the 6 font group case for each.

The overall percent correct for the algorithm using the combined Figures 14a, 14b, and 14c for the top 1000 words with the 6 font group case is 98.7% with and 99.5% without

```
V       HORIZONTAL --->                  -4 -3 -2 -1  0  1  2  3  4
E                                       ------------------------------
R  |                                -4 |  *  *  *  *  *  *  *  *  *
T  |    (*) - signifies             -3 |  *  *  *  *  *  *  *  *  *
I  |        coefficients used.      -2 |  *  *                 *  *
C  V                                -1 |  *  *                 *  *
A                                    0 |  *  *                 *  *
L                                   +1 |  *  *                 *  *
                                    +2 |  *  *                 *  *
                                    +3 |  *  *  *  *  *  *  *  *  *
                                    +4 |  *  *  *  *  *  *  *  *  *
                                        ------------------------------
                                              [a] : (4 x 4) - (2 x 2)


     -4 -3 -2 -1  0  1  2  3  4              -4 -3 -2 -1  0  1  2  3  4
    ------------------------------          ------------------------------
-4 |                                -4 |        *  *  *  *  *
-3 |                                -3 |        *  *  *  *  *
-2 |  *  *  *  *  *  *  *  *  *     -2 |        *  *  *  *  *
-1 |  *  *  *  *  *  *  *  *  *     -1 |        *  *  *  *  *
 0 |  *  *  *  *  *  *  *  *  *      0 |        *  *  *  *  *
+1 |  *  *  *  *  *  *  *  *  *     +1 |        *  *  *  *  *
+2 |  *  *  *  *  *  *  *  *  *     +2 |        *  *  *  *  *
+3 |                                +3 |        *  *  *  *  *
+4 |                                +4 |        *  *  *  *  *
    ------------------------------      ------------------------------
          [b] : (2 x 4)                              [c] : (4 x 2)

   number of agreements:
      [a] vs [b] = 24323 out of 25000 possible.
      [a] vs [c] = 23731 out of 25000 possible.
      [b] vs [c] = 24021 out of 25000 possible.
   number of none agreements between all three:
      [a] != [b] != [c] == 253 out of 25000 possible.
```

Figure 14. First Three Harmonic Groups

```
V       HORIZONTAL --->                   -4 -3 -2 -1  0  1  2  3  4
E                                       ------------------------------
R  |                                 -4 |     *     *     *     *
T  |    (*) - signifies              -3 |  *     *     *     *     *
I  |        coefficients used.       -2 |     *     *     *     *
C  V                                 -1 |  *     *     *     *     *
A                                     0 |     *     *     *     *
L                                    +1 |  *     *     *     *     *
                                     +2 |     *     *     *     *
                                     +3 |  *     *     *     *     *
                                     +4 |     *     *     *     *
                                        ------------------------------
                                        [a] : (4 x 4) - (evens terms)

      -4 -3 -2 -1  0  1  2  3  4          -5 -4 -3 -2 -1  0  1  2  3  4  5
    ------------------------------      -----------------------------------
 -4 |  *     *     *     *     *     -4 |
 -3 |     *     *     *     *        -3 |
 -2 |  *     *     *     *     *     -2 |  *  *  *  *  *  *  *  *  *  *  *
 -1 |     *     *     *     *        -1 |  *  *  *  *  *  *  *  *  *  *  *
  0 |  *     *     *     *     *      0 |  *  *  *  *  *  *  *  *  *  *  *
 +1 |     *     *     *     *        +1 |  *  *  *  *  *  *  *  *  *  *  *
 +2 |  *     *     *     *     *     +2 |  *  *  *  *  *  *  *  *  *  *  *
 +3 |     *     *     *     *        +3 |
 +4 |  *     *     *     *     *     +4 |
    ------------------------------      -----------------------------------
    [b] : (4 x 4) - (odd terms)                     [c] : (2 x 5)

    number of agreements:
       [a] vs [b] = 23978 out of 25000 possible.
       [a] vs [c] = 24289 out of 25000 possible.
       [b] vs [c] = 24362 out of 25000 possible.
    number of none agreements between all three:
       [a] != [b] != [c] == 201 out of 25000 possible.
```

Figure 15. Second Three Harmonic Groups

the Wedding Text font style. Seven out of 25 font styles produced 100.0% correct. Eight out of 25 font styles produced 99.8 to 99.9% correct. The result is a slight increase (0.1%) in overall percent correct from the 2 x 4 harmonic group case, Figure 14b, by itself.

The second three harmonic group case is shown in Figure 15. The overall percent correct for the algorithm using the combined Figures 15a, 15b, and 15c for the top 1000 words with the 6 font group case is 98.8% with and 99.6% without the Wedding Text font style. Ten out of 25 font styles produced 100.0% correct. Seven out of 25 font styles produced 99.8 to 99.9% correct. The result is again a slight increase (0.1%) in overall percent correct from the 2 x 5 harmonic group case, Figure 15c, by itself.

The final result is: to get harmonic groups which have ≥95% percent correct and are completely unique in the coefficients they use is not possible. Some overlapping of harmonic groups is required. If the restriction of being $\geq$95% is removed then three unique harmonic groups can be obtained, but their overall percent correct is never $\geq$99.7%. The combined percent correct is always better than any of the three groups individually, but it never achieves 100.0% correct.

V. Conclusion

The original algorithm used in my Master's thesis (13) clearly demonstrates the ability to recognize an entire word as a single symbol using the lower harmonics of its Fourier transform. These lower harmonic coefficients provided a feature space in which to categorize each image of a word. The difference between the coefficients establishes a basis for chosing similar and nonsimilar images. The algorithm is shown to be deficient though, in section 4.1, because it does not perform well with a large vocabulary. As the number of images within the vocabulary grows, processing time becomes excessive and performance decreases rapidly. The algorithm does display the unique property of identifying whole words as single symbols, but for use as the algorithm of a reading machine, it is marginal at best.

The solution to the vocabulary problem is solved with the use of font groups. The font groups are created by averaging the individual Fourier coefficients from similar font styles. The coefficients are originally energy normalized in Fourier space to plot on the surface of an n dimensional hypersphere. The averaging within the font groups was accomplished for each coefficient individually, and all coefficients are assumed to be orthogonal to each other. Averaging was performed using a simple combined average ($\frac{1}{n}\sum_{j=1}^{n} c_{i,j}$ where $c_{i,j}$ represents the i^{th} Fourier coefficient for each word and the case where the are n font styles in the font group). These font groups, therefore, make up the decision or output space, and the font styles make up the input space.

The variance within a font group for a particular word is computed from the (M1) distance between the average and an individual font style. The distance between two font groups is the distance between the location of one average to the other. The use of font groups is superior to the original algorithm proposed in my Master's thesis because the average distance *between* font groups is greater than the variances *within* a font group. Without font groups, the area encompassing all the locations along the n dimensional surface for a particular word (each location represents a particular font style) boarders the area encompassing all the locations of another particular word. When a location to location distance calculation is made, as in the original algorithm (section 4.1), the individual words

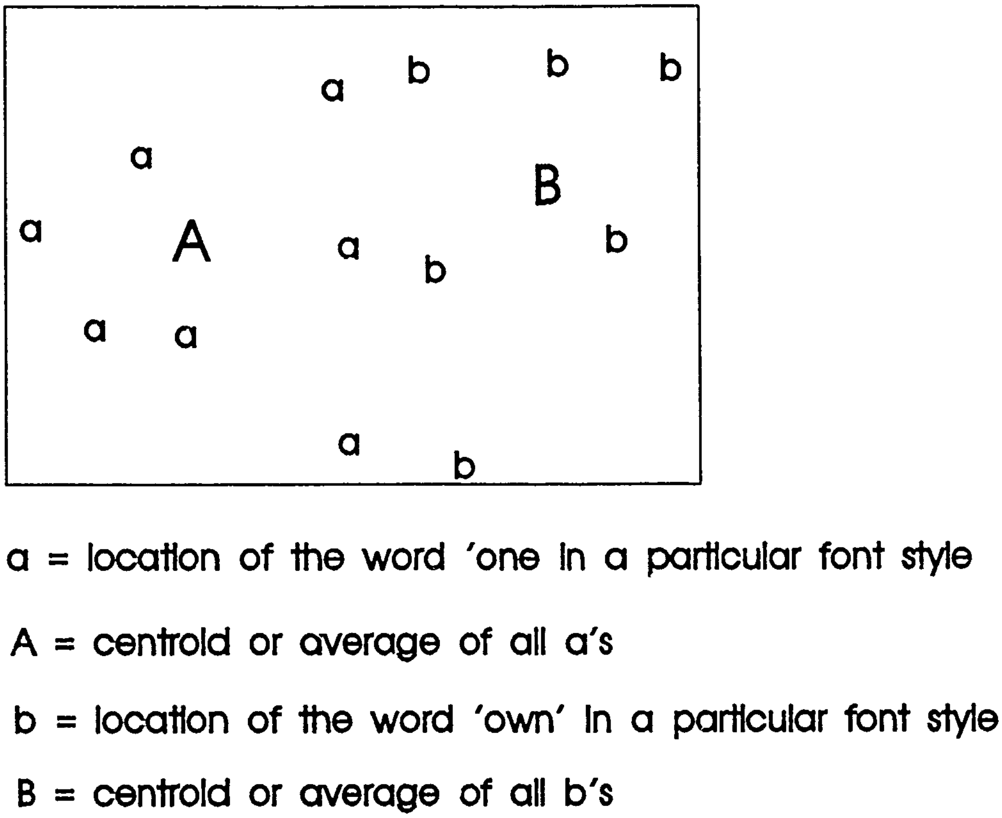

a
b
A
B
a = location of the word 'one in a particular font style
A = centroid or average of all a's
b = location of the word 'own' in a particular font style
B = centroid or average of all b's

Figure 16. Two Dimensional Representation of an n Dimensional Surface

are sometimes closer to an alternate word that is along the boarder of its area, than the same word in a different font style. But by using font groups, the nearest neighbor is defined to be the location of the centroid of the area. For a simplistic two dimensional drawing of this explanation see Figure 16.

Notice in particular the three a's and the three b's in the center of the Figure 16. If the original algorithm, section 4.1, is applied, then the nearest neighbors are not the same words (i.e., a and b are closest). However, if the algorithm used in section 4.2 is applied, then the nearest neighbor of a particular word (a or b) would be the centroid of its area (A or B), and the nearest neighbor is then chosen to be the same word (i.e., a points to A and b points to B). This is the basis of my claim that the images of a particular word in different font styles will cluster on the surface of an n dimensional hypersphere in Fourier space. The centroid, A or B, which is the average of a particular cluster, defines the coefficient values of a particular word in a single font group. When the area of a cluster becomes too large, with respect to the total number of clusters and their composition, the cluster should be split. This is represented in section 4.2.1 by increasing the number of font groups to define the output space.

Both printed and cursive text styles cluster in Fourier space. This is why the algorithm, section 4.2, is capable of recognizing both types of fonts. Block versus italicized, or, plain versus ornate, are capable of being recognized. The M1 distance rule, section 4.2.2, is currently the best (empirically determined) algorithm for chosing a match for an input word. Even though the coefficient values were created and energy normalized using euclidean space, the distance algorithm performs best using M1 space.

Noise in the input image is associated with a greater distance from a particular word's font group centroid (distance between the a's and A in Figure 16). However, because the distance between an individual word (a) and its font group centroid (A) is less than another nearby word's font group center (B), added noise to the input images (up to 50%) does not adversely affect recognition. Therefore, the algorithm is substantially insensitive to the addition of noise. In Fourier space the relative area around a centroid (A or B) versus the distance between between centroids (A to B) provides for large input variances while still maintaining well defined clusters for individual words. Noise and variation in font styles have the same effect in Fourier space. They both vary the location of a particular word on the surface of the hypersphere. With too much variance, incorrect matching occurs (a's match with B or b's match with A).

The technique used to compute Fourier coefficients in this research are scale invariant. The algorithm is proven to be substantially insensitive to noise and is capable of handling almost any font style, printed or cursive. Therefore, I conclude: the algorithm, as defined in section 4.2 and 4.3, is suitable as the basis for a whole word and number reading machine.

Appendix A. *Font Styles*

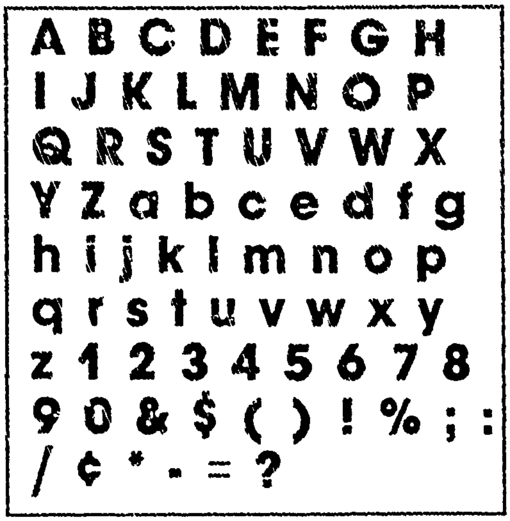


Figure 17. Avant Garde Bold Font Style

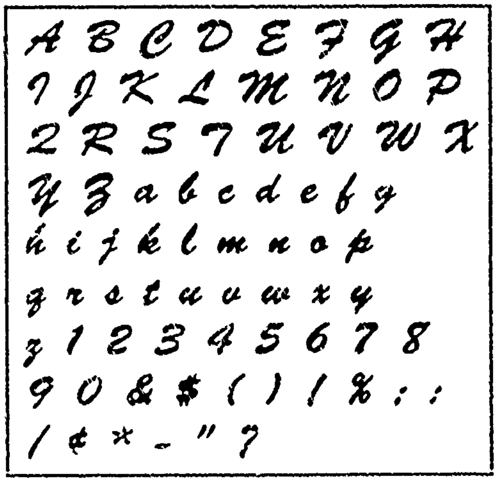


Figure 18. Brush Font Style

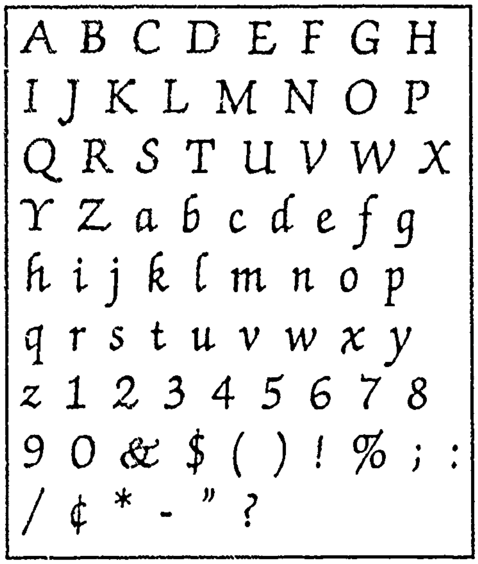


Figure 19. Zapf Chancery Light Font Style

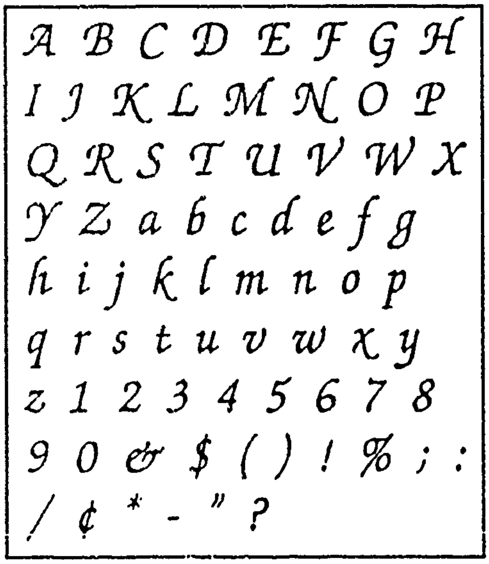
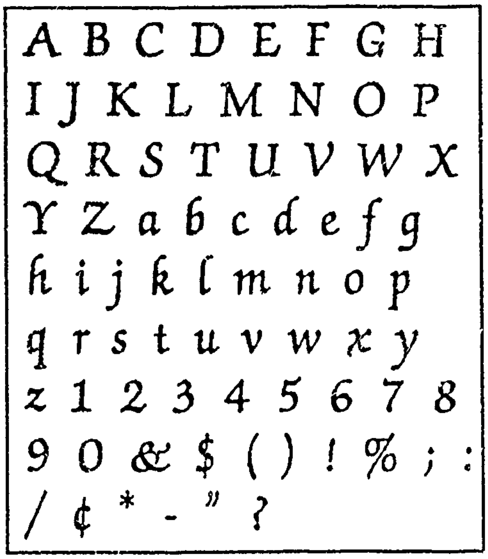
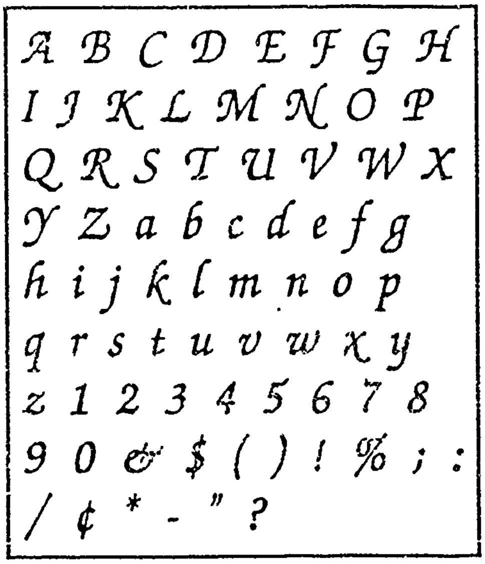


Figure 20. Zapf Chancery Light Italicized Font Style



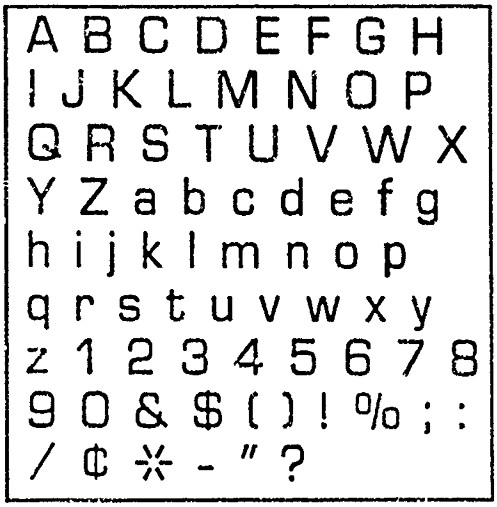
A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 21. Zapf Chancery Medium Font Style



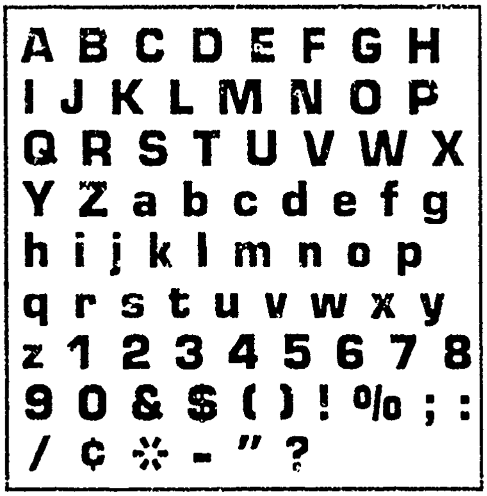
A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 22. Zapf Chancery Medium Italicized Font Style



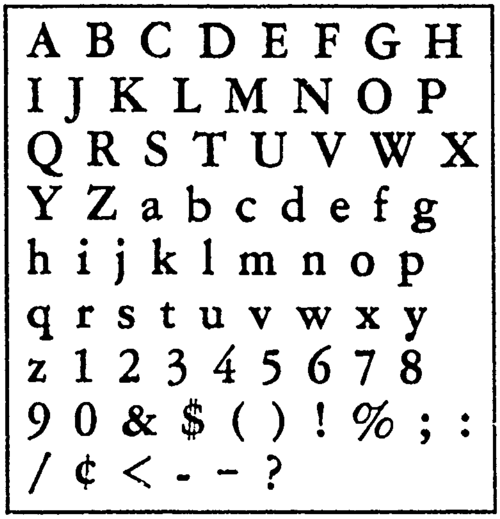
A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 23. Eurostile Font Style



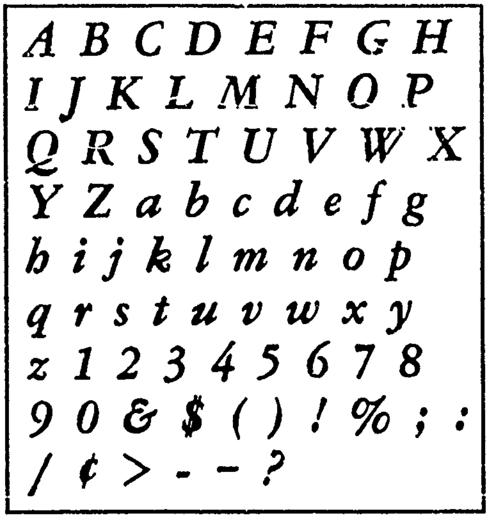
A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 24. Eurostile Bold Font Style



A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ < - – ?

Figure 25. Garamound Bold Font Style



A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ > - – ?

Figure 26. Garamound Bold Italicized Font Style

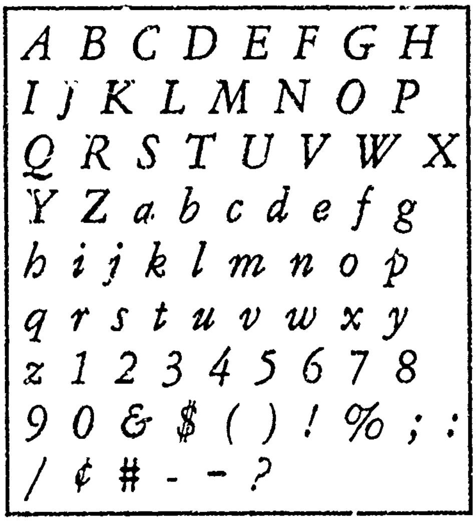


Figure 27. Garamound Italicized Font Style

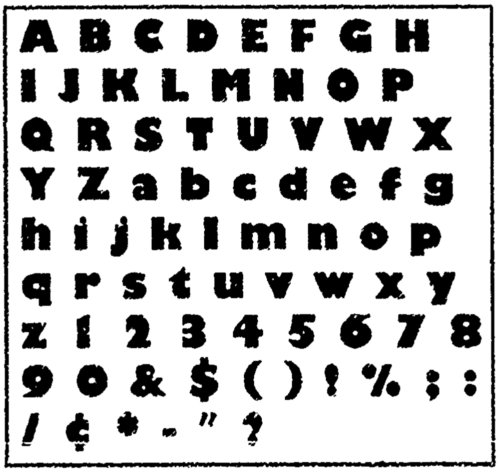


Figure 28. Gill Kayo Font Style

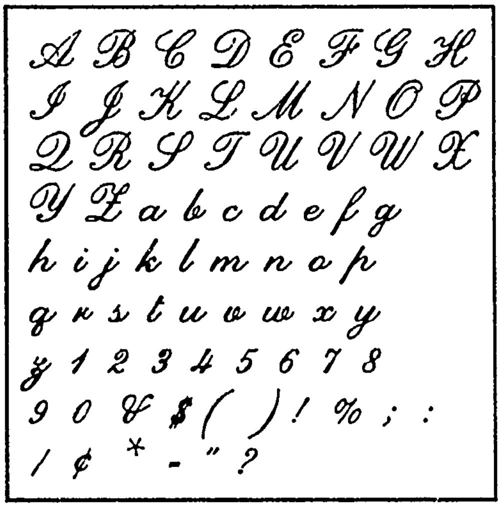


Figure 29. Helena Script Font Style

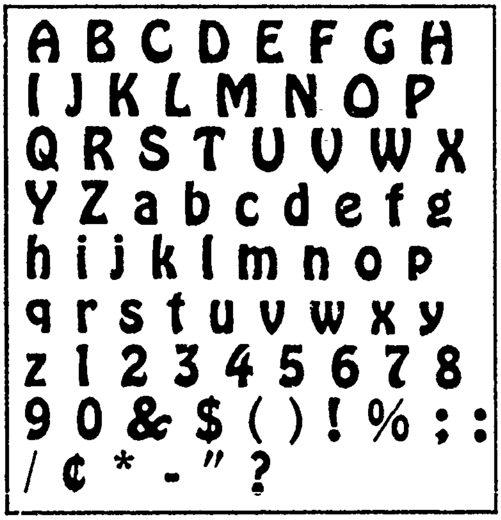


Figure 30. Hobo Font Style

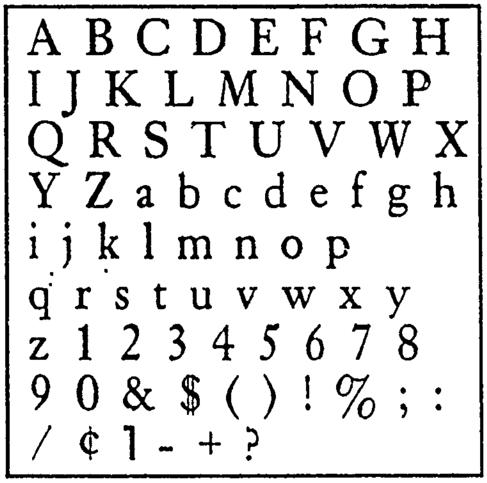


Figure 31. Janson Font Style

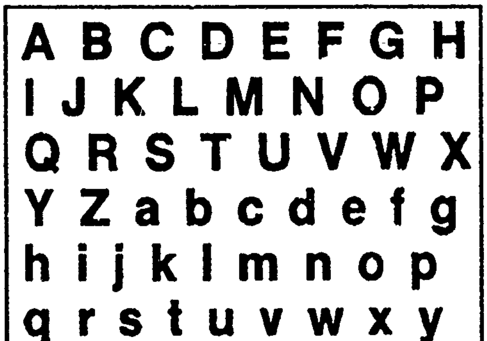
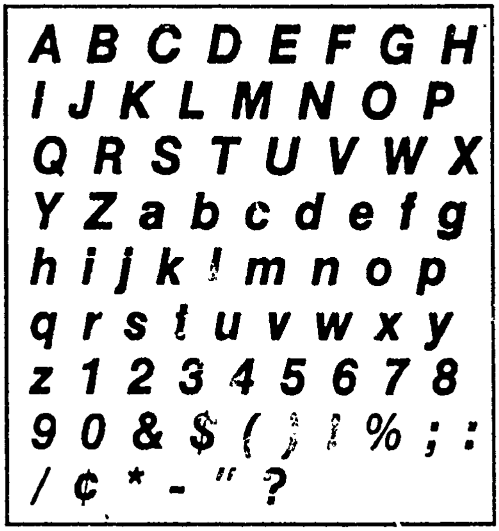
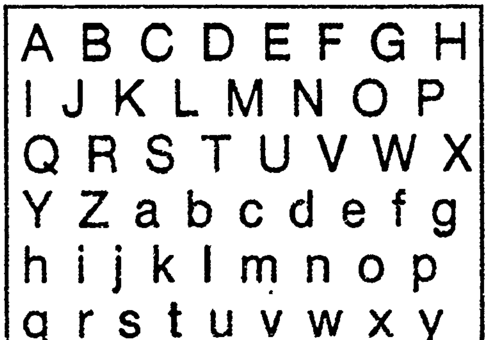


Figure 32. Megaron Bold Font Style



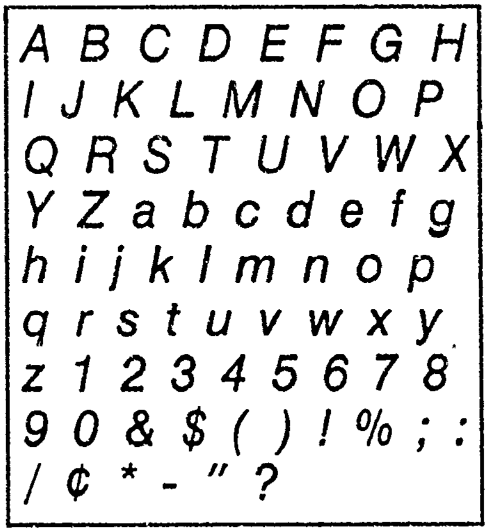
A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
*/ ¢ * - " ?*

Figure 33. Megaron Bold Italicized Font Style



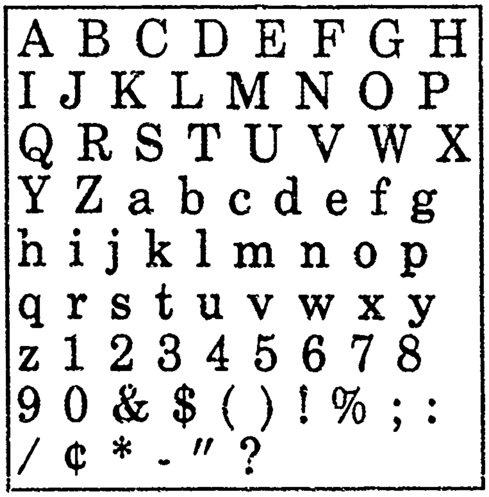
A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 34. Megaron Medium Font Style



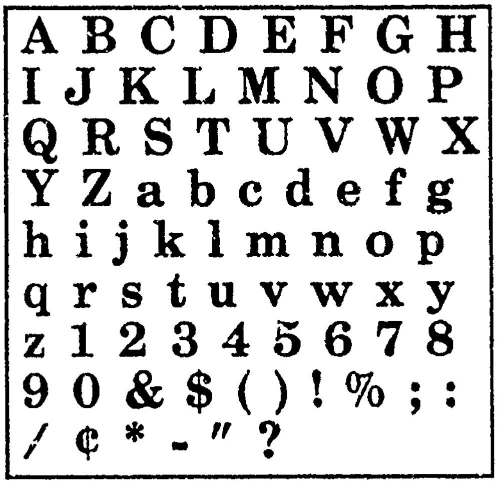
A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 35. Megaron Medium Italicized Font Style



A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 36. Schoolbook Font Style



A B C D E F G H

I J K L M N O P

Q R S T U V W X

Y Z a b c d e f g

h i j k l m n o p

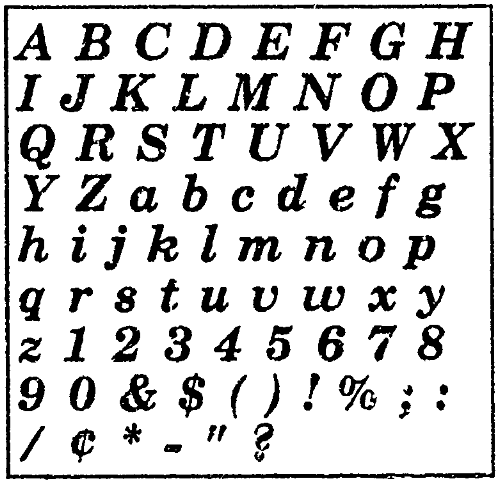
q r s t u v w x y

z 1 2 3 4 5 6 7 8

9 0 & $ ( ) ! % ; :

/ ¢ * - " ?

Figure 37. Schoolbook Bold Font Style



A B C D E F G H

I J K L M N O P

Q R S T U V W X

Y Z a b c d e f g

h i j k l m n o p

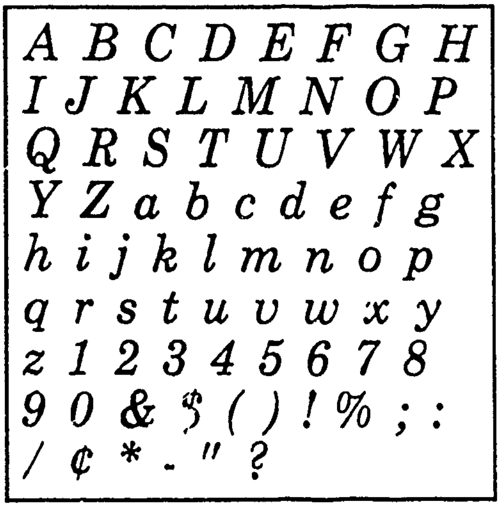
q r s t u v w x y

z 1 2 3 4 5 6 7 8

9 0 & $ ( ) ! % ; :

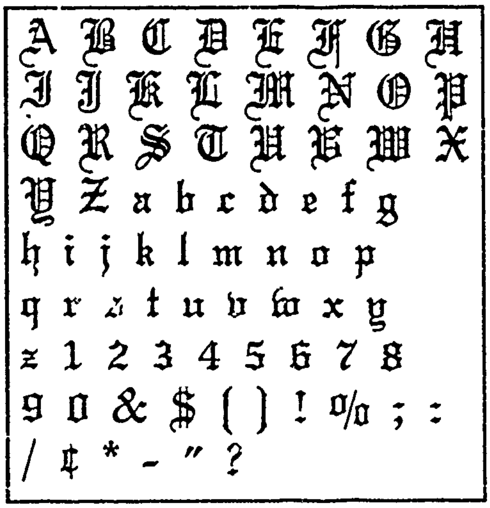
*/ ¢ * - " ?*

Figure 38. Schoolbook Bold Italicized Font Style



A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 39. Schoolbook Italicized Font Style



A B C D E F G H
I J K L M N O P
Q R S T U V W X
Y Z a b c d e f g
h i j k l m n o p
q r s t u v w x y
z 1 2 3 4 5 6 7 8
9 0 & $ ( ) ! % ; :
/ ¢ * - " ?

Figure 40. Wedding Text Font Style

Appendix B. *Computer Program for Learning Font Groups*

```
/*************************************************************************

    title: dn6lnfm.c
            < lnfm = learn new font - creates transform matrices for
              each input font, to be used with each font group.
              This uses 2nd harmonic vertically and 3rd harmonic horizontally.
              This program uses the coefficient data and computes the
      average of the coefficient values for 6 types of fonts.
      Length of the test word is the first distinguishing
              deliminator. The table of number of letters
      vs. possible matching word lengths, is as follows:

      Assumed length       Possible Matches
    1              1-2
    2 1-3
    3 2-4
    4 3-5
    5 4-7
    6 4-8
    7 5-10
    8 and up 6 and up

     by :     Mark O'Hair    3 Jul 90
*************************************************************************/

#include <stdio.h>
#include <math.h>

#define NULL 0
#define ORDER 5
#define FILTER 11
#define BLOCK 1000
#define NUMFONTS 25
#define NUMWORDS 1000
#define MAXENTR 25000
#define fabs(n) ( ((n)<0) ? -(n) : (n) )
#define pi 3.1415926535897932384626433

double **coeff_a,**coeff_b,**coeff_c,**coeff_d,**coeff_e;
double **coeff_a2,**coeff_b2,**coeff_c2,**coeff_d2,**coeff_e2;
double **coeff_f,**coeff_g,*dist;
double **coeff_f2,**coeff_g2;
int *name;

main()
{

char *font_style[35],fqword[50],character,*inputwd,*fqwords[NUMWORDS+1];

int i,j,k,l,m,n,nn,x,y,w,len_i,len_j,flag_j,word_y,num;
int ww,yy,len,nam,degree,degreev,count,count_sub,lop,size_arry;
int cnt[6],startv,finishv,starth,finishh,font,flag_loop,jmax;

double diss,dis,dissa,dissb,dissc,dissd,disse,dissf;
double mean,mag,stdd,temp,trans[NUMFONTS][FILTER*FILTER];

unsigned long ptr_position[30];

FILE *fqword_ptr,*coeff_ptr,*dist_ptr,*dist_wds_ptr;
```

```
/*************************************************************************/
degree = 1;   /** degree is the filtering amount which takes place **/
degreev = 2;   /** degree is the filtering amount which takes place **/
size_arry = sizeof(double)*121;
startv = ORDER - degreev;
starth = ORDER - degree;
finishv = ORDER + degreev;
finishh = ORDER + degree;


if ((coeff_ptr = fopen("coefficients_3","r")) == NULL)
   {
    printf("Can't open 'coefficients_3' for input.\n");
    exit(1);
   }

if ((fqword_ptr = fopen("freqwords","r")) == NULL)
   {
    printf("Can't open 'FREQWORDS' for input.\n");
    exit(1);
   }

/*****************  allocate space for fqwords   ******************/
for (x=0; x<NUMWORDS; x++)
 {
  fscanf(fqword_ptr,"%s",fqword);   /** get word from freqwords **/
  inputwd = fqword;
  len = strlen(inputwd);          /** find length of 'inputwd' **/

 if ( (fqwords[x] = (char *)calloc(len+1,sizeof(char))) == NULL)
  {
   printf("Error! can't allocate enough memory for fqwords\n");
   exit();
  }
 strcpy(fqwords[x],fqword);

 }  /** end NUMWORDS loop **/

fclose(fqword_ptr);

 j=0;
/*****************  allocate space for coeff_a    *****************/
 if ( !(coeff_a = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_a[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_a\n");
   exit();
  }

/*****************  allocate space for coeff_a2    *****************/
 if ( !(coeff_a2 = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_a2[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_a2\n");
   exit();
  }

/*****************  allocate space for coeff_b    *****************/
 if ( !(coeff_b = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_b[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_b\n");
   exit();
  }
```

```
/*****************  allocate space for coeff_b2    ******************/
 if ( !(coeff_b2 = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_b2[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_b2\n");
   exit();
  }

/*****************  allocate space for coeff_c     ******************/
 if ( !(coeff_c = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_c[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_c\n");
   exit();
  }

/*****************  allocate space for coeff_c2    ******************/
 if ( !(coeff_c2 = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_c2[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_c2\n");
   exit();
  }

/*****************  allocate space for coeff_d     ******************/
 if ( !(coeff_d = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_d[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_d\n");
   exit();
  }

/*****************  allocate space for coeff_d2    ******************/
 if ( !(coeff_d2 = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_d2[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_d2\n");
   exit();
  }

/*****************  allocate space for coeff_e     ******************/
 if ( !(coeff_e = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_e[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_e\n");
   exit();
  }

/*****************  allocate space for coeff_e2    ******************/
 if ( !(coeff_e2 = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_e2[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_e2\n");
   exit();
  }
```

```
/*****************  allocate space for coeff_f    *****************/
 if ( !(coeff_f = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_f[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_f\n");
   exit();
  }

/*****************  allocate space for coeff_f2    *****************/
 if ( !(coeff_f2 = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_f2[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_f2\n");
   exit();
  }

/*****************  allocate space for coeff_g    *****************/
 if ( !(coeff_g = (double **)calloc(BLOCK+1,sizeof(double *)) ))   j=1;
 for (i=0; i<BLOCK; i++)
 if ( !(coeff_g[i] = (double *)calloc(128,sizeof(double)) ))     j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for coeff_g\n");
   exit();
  }

/**************  allocate space for dist    *********************/
 if ( !(dist = (double *)calloc(MAXENTR+5,sizeof(double)) ))   j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for dist\n");
   exit();
  }

/**************  allocate space for name    *********************/
 if ( !(name = (int *)calloc(MAXENTR+5,sizeof(int)) ))   j=1;
 if(j)
  {
   printf("Error! can't allocate enough memory for name\n");
   exit();
  }

/******************************************************************/
  font_style[0] = "avant_garde.font";
  font_style[1] = "avant_garde_b.font";
  font_style[2] = "brush.font";
  font_style[3] = "chancery_zapf_l.font";
  font_style[4] = "chancery_zapf_l_i.font";
  font_style[5] = "chancery_zapf_m.font";
  font_style[6] = "chancery_zapf_m_i.font";
  font_style[7] = "eurostile.font";
  font_style[8] = "eurostile_b.font";
  font_style[9] = "garamound_b.font";
  font_style[10] = "garamound_b_i.font";
  font_style[11] = "garamound_i.font";
  font_style[12] = "gill_kayo.font";
  font_style[13] = "helena_script font";
  font_style[14] = "hobo.font";
  font_style[15] = "janson.font";
  font_style[16] = "megaron_b.font";
  font_style[17] = "megaron_b_i.font";
  font_style[18] = "megaron_m.font";
  font_style[19] = "megaron_m_i.font";
  font_style[20] = "schoolbook.font";
  font_style[21] = "schoolbook_b.font";
  font_style[22] = "schoolbook_b_i.font";
  font_style[23] = "schoolbook_i.font";
  font_style[24] = "wedding_text.font";
  font_style[25] = "EMPTY";
  font_style[26] = "ital";
  font_style[27] = "reg_a";
  font_style[28] = "reg_as_g";
  font_style[29] = "reg_as_gs";
  font_style[30] = "script";
  font_style[31] = "special";

for (x=0; x<MAXENTR; x++)
  {
   dist[x] = 20.0;
   name[x] = 25 * BLOCK;
  }
for (y=0; y<BLOCK; y++)
for (k=0; k<128; k++)
   {
   coeff_a[y][k] = 0.0;
   coeff_b[y][k] = 0.0;
   coeff_c[y][k] = 0.0;
   coeff_d[y][k] = 0.0;
   coeff_e[y][k] = 0.0;
   coeff_f[y][k] = 0.0;
   }

/*****************************************************************************/
for (x=0; x<25; x++)
 {
  ptr_position[x] = ftell(coeff_ptr);
  for (lop=0; lop<BLOCK; lop++)
     fread(coeff_g[lop],size_arry,1,coeff_ptr);

 /********* energy normalize based on number of coefficients used ***********/
  for (nn=0; nn<BLOCK; nn++)
   {
     mag = 0.0;
     for (k=(startv); k<=(finishv); k++)
     for (l=(starth); l<=(finishh); l++)
       {
         num = k*FILTER + l;
         diss = coeff_g[nn][num] * coeff_g[nn][num];
         mag += fabs(diss);
       }
     mean = sqrt(mag);
     for (k=(startv); k<=(finishv); k++)
     for (l=(starth); l<=(finishh); l++)
       {
         num = k*FILTER + l;
         coeff_g[nn][num] = coeff_g[nn][num]/mean;
       }
    }
  /*****************************************************************************/


   if ((x==3) || (x==4) || (x==5) || (x==6) || (x==10) || (x==11))
     {
       for (y=0; y<BLOCK; y++)
       for (k=(startv); k<=(finishv); k++)
       for (l=(starth); l<=(finishh); l++)
          {
     num = k*FILTER + l;
             coeff_a[y][num] += coeff_g[y][num];
          }
     }
if ((x==0) || (x==1)  || (x==22) || (x==23))
  {
    for (y=0; y<BLOCK; y++)
    for (k=(startv); k<=(finishv); k++)
    for (l=(starth); l<=(finishh); l++)
       {
          num = k*FILTER + l;
          coeff_b[y][num] += coeff_g[y][num];
       }
  }

if ((x==7) || (x==8) || (x==16) || (x==17) || (x==18) || (x==19))
  {
    for (y=0; y<BLOCK; y++)
    for (k=(startv); k<=(finishv); k++)
    for (l=(starth); l<=(finishh); l++)
       {
          num = k*FILTER + l;
          coeff_c[y][num] += coeff_g[y][num];
       }
  }

if ((x==9) || (x==15) || (x==20) || (x==21))
  {
    for (y=0; y<BLOCK; y++)
    for (k=(startv); k<=(finishv); k++)
    for (l=(starth); l<=(finishh); l++)
       {
          num = k*FILTER + l;
          coeff_d[y][num] += coeff_g[y][num];
       }
  }

if ((x==2) || (x==13))
  {
    for (y=0; y<BLOCK; y++)
    for (k=(startv); k<=(finishv); k++)
    for (l=(starth); l<=(finishh); l++)
       {
  num = k*FILTER + l;
          coeff_e[y][num] += coeff_g[y][num];
       }
  }

if ((x==12) || (x==14))
  {
    for (y=0; y<BLOCK; y++)
    for (k=(startv); k<=(finishv); k++)
    for (l=(starth); l<=(finishh); l++)
       {
  num = k*FILTER + l;
          coeff_f[y][num] += coeff_g[y][num];
       }
  }

} /** end x loop **/
```

```
for (y=0; y<BLOCK; y++)
for (k=(startv); k<=(finishv); k++)
for (l=(starth); l<=(finishh); l++)
   {
    num = k*FILTER + l;
    coeff_a[y][num] = coeff_a[y][num]/6.0;
    coeff_a2[y][num] = coeff_a[y][num];
    coeff_b[y][num] = coeff_b[y][num]/4.0;
    coeff_b2[y][num] = coeff_b[y][num];
    coeff_c[y][num] = coeff_c[y][num]/6.0;
    coeff_c2[y][num] = coeff_c[y][num];
    coeff_d[y][num] = coeff_d[y][num]/4.0;
    coeff_d2[y][num] = coeff_d[y][num];
    coeff_e[y][num] = coeff_e[y][num]/2.0;
    coeff_e2[y][num] = coeff_e[y][num];
    coeff_f[y][num] = coeff_f[y][num]/2.0;
    coeff_f2[y][num] = coeff_f[y][num];
   }
/******************************************************************************/

  for (y=0; y<25; y++)
   {
    for (nn=0; nn<BLOCK; nn++)
    for (k=(startv); k<=(finishv); k++)
    for (l=(starth); l<=(finishh); l++)
      {
        num = k*FILTER + l;
        coeff_a[nn][num] = coeff_a2[nn][num];
        coeff_b[nn][num] = coeff_b2[nn][num];
        coeff_c[nn][num] = coeff_c2[nn][num];
        coeff_d[nn][num] = coeff_d2[nn][num];
        coeff_e[nn][num] = coeff_e2[nn][num];
        coeff_f[nn][num] = coeff_f2[nn][num];
      }

    fseek(coeff_ptr,ptr_position[y],0);
    for (lop=0; lop<BLOCK; lop++)
         fread(coeff_g[lop],size_arry,1,coeff_ptr);

 /********* energy normalize based on number of coefficients used ***********/
  for (nn=0; nn<BLOCK; nn++)
   {
     mag = 0.0;
     for (k=(startv); k<=(finishv); k++)
     for (l=(starth); l<=(finishh); l++)
       {
         num = k*FILTER + l;
         diss = coeff_g[nn][num] * coeff_g[nn][num];
         mag += fabs(diss);
       }
     mean = sqrt(mag);
     for (k=(startv); k<=(finishv); k++)
     for (l=(starth); l<=(finishh); l++)
       {
         num = k*FILTER + l;
         coeff_g[nn][num] = coeff_g[nn][num]/mean;
       }
    }
  /*****************************************************************************/

     flag_loop = 1;

     REPEAT:
     for (k=0; k<6; k++)
     for (l=0; l<(FILTER*FILTER); l++)
        trans[k][l] = 0.0;
     for (k=0; k<6; k++)
        cnt[k] = 0;
    if (flag_loop <= 2)    /** first 2 passes are for transformation coeff's **/
       jmax = BLOCK/5;    /** passes are limited to the first 200 words     **/
     else
       jmax = BLOCK;

    for (j=0; j<jmax; j++)
    {
     for (i=0; i<BLOCK; i++)
     {

len_i = strlen(fqwords[i]);
len_j = strlen(fqwords[j]);
        flag_j = 0;

        if (len_j==1 && len_i<3)
           flag_j = 1;
        else if (len_j==2 && len_i<4)
           flag_j = 1;
        else if ((len_j==3) && (len_i>1 && len_i<5))
           flag_j = 1;
        else if ((len_j==4) && (len_i>2 && len_i<6))
           flag_j = 1;
        else if ((len_j==5) && (len_i>3 && len_i<8))
           flag_j = 1;
        else if ((len_j==6) && (len_i>3 && len_i<9))
           flag_j = 1;
        else if ((len_j==7) && (len_i>4 && len_i<11))
           flag_j = 1;
        else if (len_j>7 && len_i>6)
           flag_j = 1;

word_y = (y * BLOCK) + j;
        dissa = 0.0;
        dissb = 0.0;
        dissc = 0.0;
dissd = 0.0;
disse = 0.0;
dissf = 0.0;

 if (flag_j==1)
     {
          for (k=(startv); k<=(finishv); k++)
          for (l=(starth); l<=(finishh); l++)
     {
num = k*FILTER + 1;
dissa += fabs(coeff_a[i][num] - coeff_g[j][num]);
dissb += fabs(coeff_b[i][num] - coeff_g[j][num]);
dissc += fabs(coeff_c[i][num] - coeff_g[j][num]);
dissd += fabs(coeff_d[i][num] - coeff_g[j][num]);
disse += fabs(coeff_e[i][num] - coeff_g[j][num]);
dissf += fabs(coeff_f[i][num] - coeff_g[j][num]);
             }
```

```
         if (dist[word_y] > dissa)
             {
dist[word_y] = dissa:
name[word_y] = i + 26 * BLOCK;
       }
         if (dist[word_y] > dissb)
             {
dist[word_y] = dissb;
name[word_y] = i + 27 * BLOCK;
       }
         if (dist[word_y] > dissc)
             {
dist[word_y] = dissc;
name[word_y] = i + 28 * BLOCK;
       }
         if (dist[word_y] > dissd)
             {
dist[word_y] = dissd;
name[word_y] = i + 29 * BLOCK;
       }
         if (dist[word_y] > disse)
             {
dist[word_y] = disse;
name[word_y] = i + 30 * BLOCK;
       }
         if (dist[word_y] > dissf)
             {
dist[word_y] = dissf;
name[word_y] = i + 31 * BLOCK;
       }

       }  /** end if flag_j **/
     }  /** end i loop **/

/*****************************************************************************/

  font = name[word_y]/BLOCK;
  nn = (name[word_y] % BLOCK);

  if (flag_loop < 3)
   {
    if (font == 26)
      {
        for (ww=(startv); ww<=(finishv); ww++)
        for (yy=(starth); yy<=(finishh); yy++)
          {
   num = ww * FILTER + yy;
   trans[0][num] += (coeff_a[nn][num] - coeff_g[j][num]);
          }
        cnt[0]++;
       }
     else if (font == 27)
       {
        for (ww=(startv); ww<=(finishv); ww++)
        for (yy=(starth); yy<=(finishh); yy++)
          {
   num = ww * FILTER + yy;
   trans[1][num] += (coeff_b[nn]{num] - coeff_g[j][num]);
          }
        cnt[1]++;
       }
     else if (font == 28)
       {
        for (ww=(startv); ww<=(finishv); ww++)
        for (yy=(starth); yy<=(finishh); yy++)
          {
   num = ww * FILTER + yy;
   trans[2][num] += (coeff_c[nn][num] - coeff_g[j][num]);
          }
        cnt[2]++;
       }
     else if (font == 29)
       {
        for (ww=(startv); ww<=(finishv); ww++)
        for (yy=(starth); yy<=(finishh); yy++)
          {
   num = ww * FILTER + yy;
   trans[3][num] += (coeff_d[nn][num] - coeff_g[j][num]);
          }
        cnt[3]++;
       }
     else if (font == 30)
       {
        for (ww=(startv); ww<=(finishv); ww++)
        for (yy=(starth); yy<=(finishh); yy++)
          {
   num = ww * FILTER + yy;
   trans[4][num] += (coeff_e[nn][num] - coeff_g[j][num]);
          }
        cnt[4]++;
       }
     else if (font == 31)
       {
        for (ww=(startv); ww<=(finishv); ww++)
        for (yy=(starth); yy<=(finishh), yy++)
          {
   num = ww * FILTER + yy;
   trans[5][num] += (coeff_f[nn][num] - coeff_g[j][num]);
          }
        cnt[5]++;
       }

   }  /** end if flag_loop **/

  }  /** end j loop **/

/*******************************************************************************/
   for (yy=0; yy<6; yy++)
    {
      if (cnt[yy] >= 10)
        {
          diss = cnt[yy]/1.0;                  /** scale transfer function **/
          for (ww=0; ww<(FILTER*FILTER); ww++)
              trans[yy][ww] = trans[yy][ww]/diss;
        }
       else if (cnt[yy] > 0)
        {
          diss = cnt[yy]*10.0/1.0;             /** scale transfer function **/
          for (ww=0; ww<(FILTER*FILTER); ww++)
              trans[yy][ww] = trans[yy][ww]/diss;
        }
       else
          for (ww=0; ww<(FILTER*FILTER); ww++)
              trans[yy][ww] = 0.0;
    }
/*******************************************************************************/
```

```
   for (ww=0; ww<BLOCK; ww++)
   for (yy=(startv); yy<=(finishv); yy++)
   for (nn=(starth); nn<=(finishh); nn++)
      {
        num = yy*FILTER + nn;
        coeff_a[ww][num] -= trans[0][num];
        coeff_b[ww][num] -= trans[1][num];
        coeff_c[ww][num] -= trans[2][num];
        coeff_d[ww][num] -= trans[3][num];
        coeff_e[ww][num] -= trans[4][num];
        coeff_f[ww][num] -= trans[5][num];
      }

   if (flag_loop<3)
     {
       flag_loop++;
       goto REPEAT;
      }

 }  /** end y loop **/

/*********************************************************************
     Print out the nearest neighbor for each word
*********************************************************************/

if ((dist_ptr = fopen("results/d61nfm_3_2-1n","a")) == NULL)
   {
    printf("Can't open 'results/d61nfm_3_2-1n' for input.\n");
    exit(1);
   }

if ((dist_wds_ptr = fopen("words/d61nfm_3_2-1n_wds","a")) == NULL)
   {
    printf("Can't open 'words/d61nfm_3_2-1n_wds' for input.\n");
    exit(1);
   }

/******************************************************************************/

 fprintf(dist_ptr,"\nFONT GROUP = 6norm lnfm   SPACING = +3
                           HARMONICS USED = %d(vert)  %d(horz)",degreev,degree);
 fprintf(dist_wds_ptr,"\nFONT GROUP = 6norm lnfm   SPACING = +3
   HARMONICS USED = %d(vert)  %d(horz)",degroev,degree);

/******************************************************************************/

 count = 0;
 for (x=0; x<MAXENTR; x++)
   {
    k = (x % BLOCK);
    l = (name[x] % BLOCK);
    if (k == l)
       count++;
   }
 diss = count*100.0/MAXENTR;
 fprintf(dist_ptr,"\n\nTop choice is %5.1f percent correct overall\n",diss);
 fflush(dist_ptr);

/******************************************************************************/
```

```
 i = 0;
 count = 0;
 for (x=0; x<MAXENTR; x++)
   {
    i = x/BLOCK;
    if (i<24)
      {
        k = (x % BLOCK);
        l = (name[x] % BLOCK);
        if (k == l)
           count++;
      }
   }
 diss = count*100.0/(MAXENTR-(1*BLOCK));
 fprintf(dist_ptr,"\n\nTop choice is %5.1f percent correct excluding wedding font\n",diss);
 fflush(dist_ptr);

/******************************************************************************/

 i = 0;
 count = 0;
 for (x=0; x<MAXENTR; x++)
  {
   k = (x % BLOCK);
   l = (name[x] % BLOCK);
   if (k == 0)                    /** beginning of particular font **/
       count = 0;
   if (k == l)                    /** record if a match is found **/
      count++;
   if (k == (BLOCK-1))           /** end of particular font **/
     {
      diss = count/10.0;
      fprintf(dist_ptr,"\n%6.1f percent correct for %s",diss,font_style[i]);

      yy = (x/BLOCK) * BLOCK;
      mean = 0.0;
      for (ww=0; aw<BLOCK; ww++)
        {
         nn = yy + ww;
         mean += dist[nn];
        }
      mean = mean/BLOCK;
      stdd = 0.0;
      for (ww=0; ww<BLOCK; ww++)
        {
         nn = yy + ww;
         temp = (mean - dist[nn]);
         stdd += (temp * temp);
        }
      stdd = stdd/BLOCK;
      stdd = sqrt(stdd);
      fprintf(dist_ptr,"\n   mean = %6.2f   standard dev = %5.2f",mean,stdd);

      fflush(dist_ptr);
      i++;

    }  /** end if k **/
   }  /** end x loop **/

  fprintf(dist_ptr,"\n");
  fflush(dist_ptr);

/******************************************************************************/
```

```
  y = 0;
  for (m=0; m<MAXENTR; m++)
   {
   i = (m % BLOCK);
   nam = (name[m] % BLOCK);
   n = name[m]/BLOCK;
   if (i == 0)
       {
        fprintf(dist_wds_ptr,"\n\n**%s**",font_style[y]);
        y++;
       }
   if (i != nam)
       {
        fprintf(dist_wds_ptr,"\n%d\t%s",i+1,fqwords[i]);
        fprintf(dist_wds_ptr,"\t    %s  %s  %6.3f",fqwords[nam],font_style[n],dist[m]);
       }

   }
 fprintf(dist_wds_ptr,"\n");
 fflush(dist_wds_ptr);

 fclose(dist_ptr);
 fclose(dist_wds_ptr);


} /** end main **/
```

Appendix C. *The 5000 Most Popular Words in English*

The following are the 5000 most popular words in the English. They are listed in order of occurrance in English text with *the* being the most popular, number 1, and *lover* being number 5000.[15]

the of and to a in that is was he for it with as his on be at by i this had not are but from or have an they which one you were her all she there would their we him been has when who will more no if out so said what up its about into than them can only other new some could time these two may then do first any my now such like our over man me even most made after also did many before must through back years where much your way well down should because each just those people mr how too little state good very make world still own see men work long get here between both life being under never day same another know while last might us great old year off come since against go came right used take three states himself few house use during without again place american around however home small found mrs thought went say part once general high upon school every don't does got united left number course war until always away something fact though water less public put think almost hand enough far took head yet government system better set told nothing night end why called didn't eyes find going look asked later knew point next program city business give group toward young days let room president side social given present several order national possible rather second face per among form important often things looked early white case john become large big need four within felt along children saw best church ever least power development light thing seemed family interest want members mind country area others done turned although open god service certain kind problem began different door thus help sense means whole matter perhaps itself it's york times human law line above name example action company hands local show five history whether gave either today act feet across past quite taken anything having seen death body experience half really week car field word words already themselves information i'm tell college shall together money period held keep sure probably free real seems behind cannot miss political air question making office brought whose special heard major problems ago became federal moment study available known result street economic boy position reason change south board individual job society areas west close turn love community true court force full cost seem am wife age future voice wanted department center woman common control necessary policy following front sometines girl six clear further land able feel mother music party provide education university child effect level students military run short stood town morning total outside figure rate art century class north usually washington leave plan therefore evidence million sound top black hard strong various believe play says surface type value mean soon lines modern near peace table red road tax minutes personal process situation alone english gone idea increase nor schools women america living started book longer cut dr finally nature

private secretary third months section call greater expected fire needed ground kept that's values view dark everything pressure basis space east father required spirit union complete except i'll moved wrote conditions return support attention late particular recent hope live brown costs else beyond couldn't forces hours nations person taking coming dead inside low material report stage data heart instead looking lost miles read added amount feeling followed makes pay single basic cold hundred including industry move research developed simply tried can't hold reached committee defense equipment island actually shown son religious river ten beginning central getting sort doing received rest st terms trying care friends indeed medical picture administration difficult fine simple subject building especially higher range wall meeting walked bring cent floor foreign paper passed similar final natural property training county growth international market police england start talk wasn't written hear story suddenly answer congress hall issue needs considered countries likely wording you're earth sat entire happened labor purpose results cases difference hair meet production stand william fall food involved stock earlier increased particularly whom below club effort knowledge letter paid sent thinking using christian hour yes bill blue boys certainly ideas industrial points ready square trade addition ban deal due girls method methods moral color decided directly nearly neither showed statement throughout weeks anyone kennedy questions reading try according french lay nation programs services physical remember size comes member record southern understand western normal population strength appeared concerned district merely s temperature volume direction maybe ran summer trial trouble continued evening friend list literature sales army association generally influence led met provided chance changes former husband opened science step student aid average c cause hot month series works direct effective george lead myself piece planning soviet stopped systems theory wouldn't wrong ask clearly forms freedom movement ways worked beautiful bed consider efforts fear lot meaning note organization press somewhat spring treatment hotel placed truth apperently carried degree easy farm groups he's herself i've man's numbers plant respect wide j manner reaction approach feed game immediately larger lower recently running charge couple daily de eye performance arms blood opportunity persons understanding additional described march progress radio served stop technical based chief decision determined image main oh religion reported steps test window appear british character europe gun middle responsibility account b horse learned writing activity fiscal green length ones serious types activities audience counter forward hit letters lived nuclear obtained returned slowly specific design doubt justice latter moving obviously plane quality straight born choice figures function include operation parts pattern plans poor saying seven staff stay cars gives shot sun whatever faith pool ball completely extent heavy hospital lack mass speak standard waiting wish ahead corps deep democratic effects firm income language principle there's visit analysis designed distance established expect growing importance indicated none price products attitude cities continue determine division elements existence leaders pretty serve stress afternoon agreement applied closed easily factors hardly limited reach scene write attack drive health interested married professional remained rhode season station suggested won't

covered current despite eight i'd negro played role spent built commission council date exactly machine mouth original race reasons studies teeth unit becomes demand news prepared rates related relations rise supply bit director dropped e events james officer playing raised sides standing sunday trees unless actual clay doctor energy meant places talking thomas walk facilities filled glass hadn't jazz knows poet techniques bridge caught chicago claim concern entered fight gas happy he'd institutions popular share style cattle christ communist dollars follow heat included isn't materials radiation status suppose thousand accepted behavior books charles churches conference considerable film giving opinion primary sitting usual attempt changed construction funds hell marriage proper sea sir successful arm discussion everyone highly park practice shows sign someone source tradition wait worth americans annual authority june lord oil older project remain success fell jack leadership obvious pieces principal thin base civil complex condition dinner entirely frequently management measure mike objective parents records security structure u weight balance caused corporation d dance equal kitchen noted produced purposes clothes develop failure famous goes london names pass published quickly regard you'll active add announced bottom break carry check cover enemy greatest key king laws leaving manager mary moreover pain poetry relationship sources assistance battle bright carefully companies doesn't facts finished fixed operating possibility product spoke touch units allowed build citizens died financial inches loss otherwise patient philosophy previous require rose scientific seeing sight takes workers capital captain classes concept distribution german marked musical relatively rules shape significant stated stations variety affairs appears aware begin broad catholic circumstances collection impossible learn m named operations post proposed remains reports sex strange w bank capacity governor henry houses interests mark offered officers opening p prevent regular remembered requirements robert ship slightly speed spread team winter yesterday bar crisis drink fresh instance interesting poems presented produce train youth agreed apartment campaign cells created essential event file forced germany immediate index lives neck nine opposite provides round subjects trip watch watched explained features fully gray indicate lady offer providence recognized russian session teacher twenty atmosphere desire differences economy expression maximum mentioned procedure reality reduced sam separate studied term beside coffee edge enter fast favor literary looks mission picked secret smaller tone traditional address anode believed editor election fair follows judge laid model permit response rights solid title vocational bottle buildings difficulty formed hearing knife memory presence quiet receive region telephone watching camp dog expressed fit junior killed murder nice official planned removed rock stayed treated turning virginia vote ability berlin chapter claims contrast du faculty failed fourth frame france gain h increasing interior jewish jr leader nobody november personnel pointed positive rich selected send standards store twice advantage brief brother die discovered individuals louis membership nevertheless observed powers pulled rule valley writer writers accept allow assumed boat broke command daughter detail everybody evil faces familiar fields fig fighting hill increases items jones legal master morgan ordinary phase platform plus resources russia sharp somehow upper village wine approximately april beauty carrying chosen column compared constant factor

forth historical mercer principles proved responsible richard smiled unity universe wants aircraft box buy calls clean communism danger dogs drawn dust educational exchange f foot independence independent naturally rain revolution rome san sections shelter song sweet waited walls ancient china completed connection fashion league levels liberal lips ordered politics realize realized seek settled teachers texas weather willing actions animal application appropriate article beat characteristic directed drew dry electric eletronic emotional excellent families fifty frank horses initial khrushchev largely leading let's monday ought pictures policies proctical projects protection quick signs stands starting statements traffic won answered aside asking background career chairman communication dress estimated flat flow impact jury legs occurred paris potential reference saturday she'd sit teaching thick warm wonder you've yourself adequate arts besides birth block capable chair closely cutting declared ends experiments fingers forest gross hanover helped honor intellectual issues measured ourselves page plays properties r relief score search significance substantial achievement attorney california cell desk discussed dominant employees escape gets headquarters holding hung imagination jobs join july newspaper object objects one's passing phil rapidly sleep supposed they're typical wore aspects belief bodies credit dream empty explain grew jesus laos located maintenance matters message minimum primarily reasonable resolution site spiritual towards we'll yards argument assume benefit broken competition contact contemporary domestic dramatic experiment fellow grow happen highest kill location narrow parker powerful relation rifle shop signal sufficient tom tomorrow unusual wind achieved agencies appeal arrived assignment baby billion careful concerning cool december drove equally extreme fund greatly guests homes internal library officials please pleasure portion recognize reduce fising save senate sets speaking struggle wilson acting associated beach boston closer coast commercial continuing courses duty eat european feelings friendly governments greek ideal imagine kid la metal minister organizations possibly prices procedures shore shoulder showing soft speech tests travel vast victory we're weapons advance armed chemical circle contained contract ended existing fat friday garden goal heavily judgment keeping learning machinery maintain moon nose onto orchestra refused scale setting slow somewhere stared streets task technique text bible budget conclusion drop exist finds formula headed housing lie mine notice novel painting parties plants providing repeated roof sensitive sexual snow solution songs stories struck taste tension thirty tree tuesday ultimant uses animals avoid busy causes commerce critical dallas emphasis establish etc exercise fairly grounds hence hole india leg liked lose minor negroes neighborhood occasion orders pale perfect previously railroad remove roads roman safe sky smile stone surprised talked understood unique useful wondered afraid alive apart apparent apperence artist baseball bay bear becoming beneath birds charged combination completion congo details dictionary enjoyed entrance flowers goods informed lewis majority notes permitted processes professor replied requires sample shook somebody spot truck truly uncle academic agency apply bought chinese confidence double draw entitles evident fifteen granted guess hat intensity joined loved minds motor organized palmer pure regarded represented review september soldiers spite vision vital wage wheel wild artists begins britian components conduct conducted cross cultural demands device divided executive extended firms fort games generation identity improved inner joe

joseph l marine martin motion o pick plenty properly publication rooms runs sought sounds tall theme wagon win wished wood worry yellow attend create dear decisions description faced forget huge interpretation item jews lake machines measurements phone positions preparation putting republican risk rural seat smith soil suggest supported symbol thoughts trained unable walking absence administrative assigned august band bitter breakfast breath chest content crowd depth disease driving examples experienced experiences finding grass handle hudson january japanese largest loose minute negative payment percent practically practices prove pushed remarks sin slight spend troops vehicles version welfare wet what's windows wonderful advanced alfred bedroom centers characteristics conflict contrary correct detailed detective developing dozen element establishment eventually flesh gold hero indian introduced los raise silence telling theater trust widely abroad achieve advice ages agree angle approval arthur begun boats colors conventional cousin david devoted easter elections estate foods gradually guy investigation laughed listen necessarily nodded october opportunities papers player protestant pull rear shoulders sick situations stages stream supreme surprise throat uniform views warren waves advertising assembly automobile brilliant burning chain childhood choose conversation conviction convinced courts desired efficiency eisenhower engine expense extra extremely female fill fundamental g hills institute issued knowing latin massachusetts mention moments motors noticed pair philadelphia proud strike taught television till tiny towns welcome wooden worse acceptance consideration constitution count creative depends driver employed firmly holy impressive incident leaves measures milk millions operator partly passage payments request ride silent speaker sports tendency tragedy anger attitudes charlie co comparison concrete cry destroy drinking formal functions grand guard hearst hoped hopes integration intelligence limit liquid maintained mantle mile missile occasionally operate personality pink plain poem precisely quietly resistance royal screen she's shooting sorry suit swung tired twelve via angles aspect bills blind boards bonds concentration congregation considering cook cuba denied deny employment engaged essentially everywhere expansion expenses fears grant honest humor instrument italian lights lincoln luck mail manufactures mere models moscow movements northern numerous opera patterns periods prior provision purchase remarkable representative ring rolled safety singing skin sold soul stairs supplies surely testimony thousands unknown vacation wearing ain't anyway artery atomic author avenue award bond centuries chamber conscious creation curious dangerous decade difficulties doctrine dollar electrical encourage engineering equivalent fiction flight fought georgia identified insurance legislation liberty loan losses native opposition panels pocket precision recommended relative salt seriously shares shut superior threw trend violence wave weakness wright adopted africa alexander angry approached ballet brain calling cast charges contain containing cup curve depend diameter discovery edward elsewhere expenditures february feels ice impression includes intended interference load lucy meat medium mold mounted offers offices pennsylvania percentage prime promise promised qualities referred residential riding sheet steel sum target taxes terrible universal valuable watson accomplished acres adam admitted agent amounts answers arranged asia brush burden changing climbed collected confused confusion considerably continuous contribute developments driven em enjoy errors expensive extensive fired fun hans helping hundreds lies listed lovely mama manchester mobile mostly nearby odd opinions origin path pilct recognition sale seeking shoes slaves snake spirits suffering tables

thickness volumes warning washing wisdom younger believes bureau catch cloth coat comfort concerns consists dancing darkness dealing dirt drama emotions explanation external flying grown heads heaven identification insisted investment iron lawyer lifted liquor marketing mental mountians occur oxygen pace porch pounds rapid raw reaching reader readily recorded recreation republic resulting route salary saved separated ships suffered switch technology tend tour transportation warfare whenever year's adams anne anxiety anybody appointed bag bound civilization comment crossed demanded distinct distinguished ease editorial engineer environment excess exists express fed golden guns hardy hate holds increasingly journal linda lots muscle nineteenth obtain particles possibilities pride prison rachel reactions reduction reflected regional replaced reply seeds skill smooth sufficiently threat throw touched unlike urban varied varying wages waters weapon wire arc assumption atoms bread brothers carl communities comparable constantly continues cooling describe display distinction downtown favorite francisco funny henrietts institution involves kate limits match musicians n opposed participation pike pleased proposal queen rare rarely remaining removal representatives restaurant rough sake seed sell shift smoke societies spending steady stepped storage teach tissue vice virtually visited whereas writes afford approved atlantic automatic bars bob brings burned code combined composed conscience criticism customers dean decide democrats dependent desegregation discover drawing eleven exception existed finger focus glance goals grace guidance handsome happens highway illinois improvement inch indicates intense joy laboratory languages legislative missed necessity neighbors notion observations orleans painted papa parallel permanent personally pope presumably prominment proof psychological regarding regions rode self senator shared shear shouted stranger studying talent thoroughly thrown today's tool treasury visual walter winston acts agents allotment anywhere assured attractive authorities colleges comedy communists concert contributed controlled deeply defined derived destroyed determination emergency estimate finish forever furniture furthermore gained guest holes hydrogen ill improve introduction joint lawrence legislature listening long-range mad magazine mankind maturity mississippi mystery neutral o'clock objectives provisions rayburn recall represents revealed satisfactory selection severe sleeping soldier stick striking trails accounts agricultural arrangements attempts axis briefly bringing candidates clouds contains copy ccrresponding cotton definition destruction districts ears experimental experts father's fifth forgotten foundation glad god's handed handling haven't inevitably instant japan knees leaned mayor newspapers ohio onset organic palace paul piano pleasant pont pressures primitive processing random reception regardless relationships represent robinson sacred scheduled serving sharply simultaneously sister specifically sudden temple thompson thyroid tonight track transfer turns voices accompanied admit aim assure atom authorized banks belong blocks chicken chose cleaning colonel comfortable constructed consumer contribution core deeper definite delivered devices distant drunk edges edition effectively enormous fail feature foam fool formation gate harbor holmes hurt illusion illustrated images innocent magic male mixed mood navy noise occasional outstanding paint plot profession push questionnaire readers release reserve resulted roberts roy serves signed skills species spoken staining state's stomach stronger strongly supper survey swimming tested thanks tremendous wash accuracy affected aren't assistant attended automatically baker beings binomial bomb camera cards cash challenge characters classic coating columns conclusions crew desirable dirty doors dressed equipped error extension fellowship filling football forty guide host hurry industries intention jackson jim kinds license lying managed

mans meets mother's moves multiple nation's normally occupied outlook paintings patients peoples peter printed probability ratio satisfied schedule scholarship scientists sees shadow similarly smiling spanish stored substantially supplied susan symbols sympathy thank tough variable visiting visitors wear wise worship you'd accurate adjustment affect atlanta bench bombs calculated calm claimed clark context counties dignity disappeared eggs fish fruit grade harry height installed instructions isolated jane jumped knee latest lumber matsuo meanwhile myth nationalism output over-all owners pat patent performed phenomenon prepare presently preserve producing retired returning revenue roll routine row sad sciences sept sequence sounded stanley stores symbolic sympathetic tape tongue urged vehicle virgin washed waste wednesday world's worried yard yield abstract alternative arrangement badly beer bent bigger blame bus canada candidate clerk consequences cooperation corn crazy crime currently decades dispute divine duties dying emotion exposed facing fallen financing findings folk frequent genuine golf harvard hunting interview italy johnson keys lee lists logical measurement mechanical metropolitan mistake net ocean openly owned pencil phrase presidential protect quarter raising realistic reasonably receiving reporters returns roles samuel seldom senior sentence shortly sing smell stretched sugar suggestion suitable swept tears tells tends tied tools vary visible we've worst accident adjusted admission advised affair alert andy artistic attempted benefits blow bone branch branches bride burst campus catholics charter child's chlorine classical connected damage demonstrated determining drill elected equation examine falling farmers fatre favorable fewer filed fly funeral gift grave guilt harmony healthy inevitable involving jacket jess leads lunch massive matching missing mountain namely naval nights owner parked pathology performances poland precise presentation presents prince prokofieff quantity rector refected rev rice scheme slavery stems strictly substance succeeded suffer survive symphony thereby thermal thursday tragic unfortunately violent awareness beef castro chandler circles coal collective conception concluded confronted cooking courage covering covers crowded curt debate depending discussions eastern eating effectiveness efficient elaborate electronics emission engineers excitement factory falls farther fishing gardens gathered gesture gorton harold heading household howard inadequate indians initiative kids lacking loans long-term mills missiles mud museum nakes pa partner plastics poets promote reflection remarked remote romantic salvation scotty shouting skywave slipped so-called spots stuff survival swift t temporary testing they'll transition universities van variation we'd weak wedding williams accordingly allowing articles barely basement bird ceiling checked christianity colored competitive composer consequently conservative considerations counter dancer dancers dave decline defeat ending enterprise evaluation extend extraordinary fallout films finance fourteen frequencies gallery gently he'll helps horn identical invariably involve juniors kansas knocked letting lightly locking maid mainly markets mature movies muscles outer pacific pages panel parking perfectly plastic poetic protected recording reducing remark respectively ruled russians saline secondary selling seventh shock softly sponsored starts strain structures studio successfully territory tossed trail troubled tube v winning absolute alex allies altogether associations blanket buying carbon citizen comments complicated concentrated consciousness consequence controls cried crucial cuts dartmouth dates dealers deliberately density dimensions directions doctors dreams eddie electron encountered era et excessive expert felix fence flux franklin frontier gay graduate grinned historian hoping impressed instances islands johnny lane listened locked louisiana meal

measuring medicine miriam mixture network occurrence preceding propaganda purely radical ranging reform replace representing reveal root sacrifice secure sen shakespeare sharpe sheets skilled slave sovereign split stable strip surprising suspect suspended they'd unconscious virtue voting widespread woodruff worker albert allied ann anxious apparatus applying argue argued aleep bare barn belt brannon bronchial builder carleton commonly constitute contributions cow creating delight divorce drying ear ecumenical encouraged entertainment eternal ethical examination exciting extending fabrics false fees furnish glasses guilty helpful ignored jet jurisdiction lesson lieutenant lighted magnitude merit mighty modest morality morse movie nowhere perception perform petitioner players poured precious pressed prestige proportion proposals questioned recovery regulations reminded republicans residence samples sang scenes sewage shapes sherman shorts shots signals silver solutions sons stars stem subsequent suburban suggests tasks testament theatre threatened transferred trips unions utility vigorous volunteers absent advantages african appointment arise brooklyn bullet calendar clarity closing cloud colony commander committed communications compare consistent convention cure dawn demonstrate designs dining diplomatic discuss dried drugs encounter enthusiasm examined exclusive expanding fled folklore formerly freight gathering gentleman hal hanging happening harris hated humanity innocence irish journey judgments ladies laugh libraries limitations losing maintaining marks mechanism meetings mickey mines minicipal newly offering optimal passion paused polynomial pot pound powder prayer president's prize profit promptly quarters ramey rendered roosevelt sand santa satisfaction sensitivity sergeant shade southeast sovereignty specified stained surfaces talents tea textile tight tons upstairs verse warmth witness worthy wound yankees absolutely acquire aids approaching builders butter cady cap chin christmas clayton clinical combat company's conceived concepts consisting customer dan davis define delaware delicated discipline distributed dull eager enemies exact excuse festival fiber flew fred friendship frozen gentle germans grain greenwich holder horizon hughes imagined in-jury insist jefferson julia laughing literally magnificent marriages marshall minimal mirror myra newport observation occurs operated oral ours outdoor passes peculiar permission permits pistol placing prefer prevented prevention profound publicity publicly pulmonary pursuant ranch refer reorganization reputation requirement reserved responses restrictions roots rushed scattered scholars scope seconds shayne shirt shoot shopping slept submarine suite supporting surplus surrounding suspicion theological upward utterly veteran victim voted weekend wherever wings women's acquired aesthetic anti-trust appreciate arlene assist bath beard bears billy bridges card cavalry cellar charm climate concerts contest controversy coolidge critics delightful desperate disaster disturbed eileen ekstrohm electricity eliminate emerged entry establishing exceptions feeding fist frames frightened gear greg gyro handled hang helva identify ingerent instruction instruments intelligent invited jew johnnie justify kennedy's kingdom landing legend liberals lively marshal meals mitchell mount mutual mysterious outcome overcome palfrey part-time patchen paying peaceful perspective phenomena philosophical planes pointing preferred premier promotion quoted recalled register released repeat retirement revenues sarah sessions settlement sixth snakes sophisticated southerners staring stockholders storm stretch switches tangent temperatures threatening traders treat trembling unhappy urethane variables velocity wars widow zen abandoned aboard accused adult alec allowances amateur applications approaches attached attacked attracted aug barton bearing blanche breaking cancer carolina cents cigarette cocktail component composition conductor conferences constitutional contacts continually continuity corporations correspondence coverage critic dealer delayed demonstration departments destructive detergent devil dilemma

disk eugene evidently exhibit exploration exposure faint flexible fog fortune generous glanced grateful harm hired honey houston impressions inspired intervals jersey lands lonely magazines magnetic marginal mothers nick nixon noon northwest observe operational owen pack painful parade partially patrol penny pile pittsburgh pond pressing proceeded productive prospect pulling pupils racial rational recommend reflect regiment responsibilities ritual saddle shelters stadium star structural subtle succession suits terror tilghman tim torn trading transformed trustees twenty-five vague vien viewed vivid wally ward wildly woods yeah yours absorbed academy access accomplish accurately actor advisory aimed al angels announcement arrive assembled astronomy automobiles backed barrel bend biggest bore brave broadway categories chances charming cheap cited civilian clubs coach consisted contracts criminal cycle declaration democracy depression desires diffusion draft drivers drug employee entering enthusiastic estimates exclusively explicit expressing factories firing ford forgive full-time functional heating honored illustration insure interpreted jan jump leather managers manufacturing masters mathematical meaningful mexican moore motel narrative nearest neighboring nervous norms occupation oct peas phases portland preliminary probable promising prospects puerto qualified rank reaches realism realization recommendation relieved rigid roughly ruling scarcely seated seized seventeen sitter slid specimen stupid subjected swing tail tended theresa tractor tribute tubes undoubtedly utopia weekly wholly wines wishes workshop zero adults agriculture amendment anti-semitism anticipated arrival assessment assumptions attempting attending authors bases beliefs belly boating bobby bowl brown's burns cabin casey cat category chairs champion channels children's circuit civic cleared colleagues compete continuously controlling craft crystal curiosity dances deck dedicated degrees discrimination displacement dive don douglas eighth empirical enable encouraging excited exercises expectations farmer fibers flower fogg fraction furnished gen generations genius giant gin governmental grades habit happiness harder hearts heels heights historic hollywood hungry hurried imitation incredible insects inventory jean justified killing lawyers lengths lift lighting lock luncheon madison maggie manufacturer maryland mason memorial midnight monthly musician noble orange originally oxidation pete pip plaster plates plug protest publications quiney radar reflects refrigerator regime registered registration relevant resumed rifles rocks ruth savings searching select sentiment settle sharing sheep sink spare spencer stern strategic stressed stuck substances substrate suggestions sweat tennessee thinks tie trace ultimately unexpected variations victor wake westminster whisky whispered worn wounded adding ah alaska alienation altered ambassador ambiguous america's appreciation architect aristotle attacks aunt auto autumn backward balanced baltimore belongs bid blues bobbie bombers bother capabilities capitol carries casual chart chiefly complained congressional conspiracy convenient dealt deegan describes desperately destiny di doubtful dressing drinks earliest economical eighteenth elaine eliminated empire engagement exhibition expects fault foams forests formulas fortunate freely frequency gang grows gulf hen herd hide hits hypothalamic implications insight intentions investigations joke laughter lo loaded loyalty meanings melting merchants mess miami middle-class miller moderate motive nerves novels obligations occasions overseas ownership palm panic participate patience physics phsiological pitch planets plate opossessed posts preparing racing ralph recommendations refund regularly rehabilitation relatives reliable resist respects retained rhythm sampling sandburg savage servants shell shouldn't sighed sixties soap souls spectaculat sphere sponsor statistics steadily sticks strategy substitute successes suited surrender targets teams thrust tip tire totally traveled triumph troubles

trucks uncertain uneasy unfortunated valid vienna voluntary warned wealth weren't woman's yelled acceptable accepting addresses anglo-saxon anniversary arbitrary associate availability beam behalf belgians ben bold breathing bridget bullets certainty characterized cholesterol circular city's classification cm colonial colorful commodites competent complement computed congressman conversion cope crack crises comwell crossing dare dedication defend definitely delay desert despair detroit diet dishes displayed displays drawings dynamic educated enjoyment envelope fans faulkner flash fluid forming francis garage gentlemen giants glory governing habits helpless heritage heroic hesitated hoag inclined indirect inspection intermediate intimate jail john's johnston joyce katanga kay keeps keith killer launched linear loop lowered lucky luxury marble mars masses mate maude melody merger michigan milligrams missouri mode monument morris neat noy nuts obliged occurring painter particle partisan passengers patient's pause persuaded pertinent philip pitcher planet planetary podger port possession prairie prisoners procurement profits prospective protein punishment questioning races rang rent replacement resolved respectable respond reveals reverend revolutionary russ saving scared screw shaking shame shining shu sidewalk sixty skirt smart socialist speeches springs startled steele stiff stumbled submitted summary surrounded suspected tale tales taxpayers taylor telegraph theirs theoretical thorough traditions trends ugly unlikely urge urgent utopian verbal vermont vernon wagner warwick wheels winds witnesses wives wondering abel accordance adjustments alabama alike allen alliance amazing anticipation anyhow arnold aroused attain authentic awake basically bet binding biological blonde bones boots borden border boss brushed buck bundle cafe cape cathy chapel cheek christ's clock clothing compromise conditioned confirmed converted convictions cooperative crash crawled cream creatures crop decent disposal distinctive doc dolores dominated donald emphasize endless enforced expanded explains fantastic fascinating feb figured fitted florida foil fortunately founded fractions freddy gather grabbed grains grants greeted grip guided guys happily hasn't hatred hidden historians hospitals hotels ideological illness improvements impulse inc indication injured input intervention invention invitation judges jungle k landscape laura lean leaped legislators likes listeners lobby loud lungs manage manhattan mathematics merchant mercy michelangelo minority motives mustard negotiations nest newer ninth notable nude observers oedipus okay orderly overwhelming package parks passages peered physically pioneer pipe plato poverty probabilities promises pupil purchased pursue puts quarrel ranks reactionary receives relating renaissance repair reporter residents responded retail rises rush sailing sauce secrets shadows sheriff sixteen skyros slide slim socialism solely solve splendid stake strikes strongest struggling styles submarines suitcase supplement tactics temporarily tent theories thereafter tones tooth tournament transformation trap treaty trim twentieth underlying vacuum voters votes warrant wit worries achievements addressed affects airport allows ambition amen appeals applies arrest arrested assert assessors assurance attract avoided blowing brass broader businesses canvas caution combinations commissioner companion comprehensive condemned consistently continental convenience corporate cottage crown cuban curves dairy dawned dated daytime deadly decisive delivery demanding depths devotion dim directors discharge diseases distances distinguish documents drank dreamed earnings elementary emperor enforcement entries essay ethics eve exceed exceptional fatal fathers fats fever figs filing flood frederick fury gains glued gov gaurds guitar ham haney hay helion hostile hypothalamus ignore immortality imposed individually infinite insistence instantly killpath label lacked ladder lap letch lid livestock lodge lover

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The Fourier transform is investigated as a means for developing an optical reader capable of reading a large vocabulary without segmenting the image of a word into individual characters. The reader is capable of reading printed and cursive font s'yles, is scale invariant, and is substantially insensitive to noise. The image of a particular word is treated as a single symbol; the two dimensional low frequency Fourier coefficients (assuming *n* coefficients are calculated) define the word's location on an *n* dimensional hypersphere of unit radius. The distance between individual locations (words) categorizes similar and dissimilar words. The smaller the distance, the more similar two images are. Multiple images of a word using various font styles form a unique cluster on the surface of the hypersphere. The distance between clusters (different words) is greater than the distance across a cluster (same word in different font styles). Therefore, by using the centroid of these clusters to build a library of words, input or test words match to the nearest cluster centroid using a minimum distance calculation. This algorithm is capable of correctly recognizing at least 5000 words using 24 various font styles (120,000 individual images).

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